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AN EVALUATION OF THE HYDRAULIC PERFORMANCE OF TRICKLE IRRIGATION SYSTEMS IN ALBERTA

by

© SVATOPLUK JONAS Jr.

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "An Evaluation of the Hydraulic Performance of Trickle Irrigation Systems in Alberta" submitted by Svatopluk Jonas Jr. in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

Trickle irrigation is a comparatively new method of irrigation which is finding rapidly increasing use in all parts of the world. An evaluation project for trickle irrigation and its suitability for special crops in Alberta was initiated in 1972 and has been carried on since that time. In 1973 the project was further developed and eight different systems were tested at the Brooks Horticultural Research Center in Southern Alberta.

Two "Double Hose" systems, one "Porous Hose" system and five different types of laterals with emitters were tested throughout the entire season. Pressure and discharge were measured to obtain the hydraulic performance of the trickle laterals. The results are summarized in tables and graphs. Best fit curves were computed to obtain a relationship between the pressure and lateral length, and also the discharge and lateral length. Four nomographs were constructed to assist a designer of trickle systems in estimating the length, discharge and application uniformity of the system. Knowing the operational characteristics of eight different types of trickle irrigation can help in choosing the best system to fit a particular area and a particular crop. The tests showed that some of the systems are not suited to Alberta needs and conditions. Others, which may be suitable, have variable characteristics and therefore need to be chosen to fit particular conditions. Also, an economic analysis can help in choosing the proper system which would save water, increase yields and reduce labor with future automation of the systems.

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INTRODUCTION

Irrigation is most important for agriculture in arid regions. Supplementary water is essential in these areas as agricultural production would not be possible without irrigation. Some older civilizations have survived in these areas by building irrigation projects and irrigating the land, or by using annual floods of the larger rivers for irrigation purposes.

The function of irrigation is to add water to the soil and so replenish the moisture which is used by plants and that which is evaporated to the atmosphere. At the same time, the water cools the soils and leaches salts out of the root zone.

Real progress and a revolution in irrigation techniques took place when engines were invented, especially internal combustion engines and electric motors. Man did not need to rely entirely on the natural configuration of land or on animal power. Efficient pumps could be used and finally, with the invention of sprinklers, rain could be simulated.

At the present time, the population explosion is causing a world shortage of food despite the fact that agricultural production has increased several fold in the past two decades. The demand for agricultural products is still not fulfilled. There is a necessity to find new methods of food production and to use water and fertilizers more efficiently in order to increase yields. Increasing demands for agricultural production also stimulate growth of associated industries. With the growth of industry, natural resources become more depleted.

It is here that agriculture and industry have a common interest - the need for water.

There are some countries at the present time where the shortage or water is not considered to be an important problem. With the aforementioned industrial growth and prosperity in agricultural production, even these water-rich countries must control their resources and save water. One of the possible solutions is more efficient use of water for irrigation purposes. The wide use of sprinkler irrigation with precise scheduling is one way to limit water use. The use of new irrigation methods and techniques is another way to save water. Countries which lacked water were the first to be forced to take precautions to preserve their water resources.

The concept of using small quantities of water in the form of drops is not new. By using this method it is possible to use only one-half (in some cases one-tenth) the quantity of water previously used for furrow or flood irrigation. Researchers discovered that yields increased considerably and the labor needed decreased. Also, poor quality water can be used, especially in areas where the water has a high salt content.

With the first successful results from trickle irrigation trials the irrigation industry started producing new types of equipment and so the new method of irrigation was born.

Trickle Irrigation, Drip Irrigation or Daily Flow are the common names for this method of slowly releasing water under low pressure and discharge. Water is measured, not in gallons per minute but, in gallons per hour. With the small applications, the daily

use of moisture can be replaced and therefore the system will be in operation for several hours a day. In some arid areas continuous irrigation for the entire growing season is required. The application rate and amount depend mostly on climate and on soil characteristics.

Trickle irrigation, however, is not adaptable to all kinds of crops. Because of the permanent nature of the system only row crops, orchards, small fruits or ornamentals are presently considered suitable for this type of irrigation. The capital cost of such a system can be relatively high and therefore only high value cash crops are economical at the present time. The system can be readily automated so that control of the soil-plant environment becomes a distinct reality.

In Alberta, some special crops have reached the stage of commercial production and even where there is no shortage of water, trickle irrigation could become a suitable method of irrigation. This thesis will deal with several types of trickle irrigation systems and their suitability in Alberta.

The objectives of this study were to analyse:

1. The operational performance of several different systems;
2. The hydraulic parameters which can be used for design of trickle irrigation systems.

REVIEW OF LITERATURE

New Method of Irrigation.

After many years of using the traditional methods of irrigation, new and better methods are being developed. One of the latest methods is trickle irrigation. By definition, trickle irrigation is: "The daily maintenance of an adequate section of the root zone of a plant at, or close to, field capacity during the growing and productive cycle" (19).

Trickle irrigation was developed from the needs of agriculture. Areas with a limited water supply and an expanding agriculture production have experienced a shortage of water. In some areas, the use of water by sprinkler irrigation was still too high and it was desirable to find a system which would use relatively small quantities of water and operate under relatively low pressures. In the 1960's the use of systems with these operating characteristics were reported (19).

Origin of trickle irrigation.

The idea and principle of trickle irrigation is not new. In the 1930's Dr. Symcha Blass observed a tree on his neighbour's property which was outgrowing all nearby trees. The tree was being irrigated from a leaky pipe which ran close to the tree. The commercial application of this idea was restricted because of the lack of suitable materials. Metal pipe would have been too expensive. The idea became feasible when inexpensive plastic pipe was produced. The development work of Dr. Blass started in 1959 when he invented and patented the first emitter which was calibrated to allow a certain amount of water

to be released from a line over a period of time. In 1947, another Dr. Blass from England, introduced a form of drip irrigation for a greenhouse. This technique has now been developed in Europe, Australia, New Zealand, South Africa and the United States during a short period of time (3).

Advantages of trickle irrigation.

Trickle irrigation is a method for which many claim the advantages greatly outweigh the disadvantages. This system should be an "ideal" system for certain types of crops. The advantages of a trickle irrigation system can be summarized as follows (4):

1. Uniformity of irrigation. A well-designed system provides a high uniformity of irrigation. All outlets (emitters) emit water at nearly the same rate. The flow from an outlet is easily measurable in the field and therefore the precise amount of water can be applied. This is very difficult with furrow irrigation and quite difficult with sprinklers. The distribution is never affected by winds.

2. Water savings. Trickles wet only a certain area and a certain volume of the soil profile. Evaporation losses are therefore considerably reduced. Because of controlled discharge no runoff occurs. The growth of weeds between crop rows or between trees is reduced. Transpiration is limited and water savings from more uniform irrigation are obvious.

3. Soil and water salinity. With trickle irrigation, more saline water can be used, and more saline soils can be irrigated than under other methods. One explanation given is that trickle irrigation does not allow the soil to dry

out which causes an increase in salt concentration. Such an increase in concentration causes a reduction in the availability of water to the plant and may also create toxicity effects. At high soil moisture contents, the salt concentration remains at a low level.

4. Labor. Since a trickle system is a solid set system it has certain advantages. Labor, such as required to move pipes for a sprinkler system or furrow irrigation, is not necessary. The trickle method requires only slightly more labor than the solid set sprinkler system because of more frequent irrigations. On the other hand, better weed control lowers the labor and operational costs.

5. Crop yields. Many reports of yield increases have been published but some results are not scientifically valid. In some areas the yield increases were considered significant. It is unlikely that the trickle irrigation would cause a decrease in yields as compared to other methods. The faster establishment of young trees and vines is possible with this type of irrigation. Young trees have shallow root zones and more frequent watering is required.

6. Equipment. Use of plastic materials for main lines, laterals and drippers reduces the cost (compared with permanent sprinkler systems). The low capacity and low pressure allows the use of small pumps and therefore there are some cost savings.

Disadvantages of trickle irrigation.

According to Cole (4), the disadvantages can be summarized as follows:

1. Application of amendments. On acid soils, where control measures are necessary, difficulties arise because ameliorants like gypsum or lime are not soluble in water and cannot be put through the system.
2. Leaching of fertilizers. In well-drained soils, water from an emitter moves vertically downward more rapidly than horizontally. Soluble nutrients,particularly nitrogen, can be leached out of the root zone and nutrient deficiency could result. One solution can be the application of small amounts of nitrogen fertilizer with water to replenish the soil nitrogen moved downwards.
3. Salt accumulation. Irrigation on soils with high levels of salts may cause salt accumulation at the edge of the wetted zone. Heavy rain can cause these salts to move into the root zone area.
4. Dripper blockage. The diameter of emitters varies, on the average, from 0.02 in. to 0.04 in. Solid particles or algae suspended in water can block these small orifices. Efficient filtration is necessary. The cost of filters increases the cost of the system considerably. Many types of filters are used such as the sand filter and wire mesh types. Water is sometimes rich in iron or carbonates, especially water from wells. In this case, a special process for removal of these substances must be used. Periodical flushing of laterals to

clean out sediments may be required.

5. Restricted root zone. Trees under the trickle irrigation can develop shallow root zones due to the small wetted zone around the drippers. A small root zone will result in poor anchorage. In poorly drained soils, roots can be damaged due to waterlogging. The root zone may be too small to store sufficient nutrients for the tree's requirements and also the trees will be less adaptable to a change in irrigation method, if this is desired.

Results from trickle irrigation trials.

Increased yields with lower water use have been reported from many countries such as Israel, Australia, Mexico, South Africa and the United States. In 1967, results from Israel reported a 167% increase in yield for tomatoes, 180% for melons, 100% for peppers and 233% for sweet corn, as compared to furrow irrigation (8). Strawberries in California had a better-sized fruit when using trickle irrigation and a 144% yield increase at final pick, compared with the standard furrow method (8).

Similar results of increased yields are reported from vegetable growers. In San Diego County, California, the first tomato trials started in 1970 (13). The trial showed significantly larger fruit size from trickles than from furrow irrigated plots. There was also a difference in yield with a much lower use of water from the trickle plots. Savings of water and labor can equalize the high initial cost of equipment.

A tomatoe and bean trial was conducted in El Salvador (12). In

this country, where seasons are long and dry, the cost of pumping water is very high. Water must be pumped from underground reservoirs 120 ft deep. In the experiments there was no significant difference in yield among irrigation methods. In the trial evaluation, however, where the cost of water was taken into consideration, there were large differences in the net income from the above mentioned crops. The estimated income from tomatoes was twice as much with trickle than with furrow irrigation.

Many optimistic reports have come from San Diego County in California (9). Citrus, avocados, peaches, apples and many other special crops are being trickle irrigated with great success. According to the Drip Irrigation News (9), some 60,000 acres will be under drip irrigation in the United States prior to the end of year 1973.

Soil Moisture Distribution and Salinity.

With furrow and sprinkler irrigation, water is spread quite uniformly over the entire ground surface. Trickle irrigation, due to the equally spaced orifices, applies water only to the rooting area of the plants. This type of application usually results in a circular shape on the surface of the soil. The development and shape of this pattern depends on the emitter discharge rate and the type of soil. The discharge rate should not exceed the minimum soil infiltration rate. The soil beneath the surface appears to be wetted the same way as on the surface but the shape can vary considerably. Depending upon the soil type, the pattern can assume an 'onion', a 'strawberry' shape or the shape of a sphere (25).

Wetted pattern and salinity.

Because a trickle system operates almost continuously throughout the growing season, or at least the irrigation intervals are very short, salinity should not be a problem. Irrigation water leaches the salts out of the root zone and therefore the highest salinity level is around the edges of the "spheres" or "cones" of wetting (15).

Goldberg and Shmueli (10) examined the salinity data for a grapevine plot. The soil profile was classified into three salinity zones.

1. An upper zone where salinity increases in the direction of the trickle orifice and in the direction of the soil surface.
2. An intermediate zone where salinity values are in the low-medium range.
3. A lower zone where salinity increases with soil depth and with distance from the trickle orifice.

The salinity in the first zone is caused mainly by evaporation from the soil surface. The roots, however, are concentrated mostly in the intermediate zone with a low or medium level of salts. No roots occur and no extraction of moisture takes place in the lower zone.

Additional research on vines confirmed this theory of the three salinity zones. An isolated pocket of accumulated salts adjoined the surface and secondly, the deep accumulation of salts was at approximately three feet depth (11).

Investigation of a salinity problem was part of a project carried out by Patterson and Wierenga at New Mexico State University (21). They found, surprisingly, that salinity between the crop rows

was higher than expected, but the difference was not significant at the 5% level. Salinity sensors showed an increase in salinity close to the surface. A rapid decrease in salinity, however, was noticed in the fall after rainfall. The rain leached salts to the deeper zones. After applying 200 mm (7.9 in.) of water as a pre-irrigation, the salts were leached away from the trickle lines.

There was some salt build-up above the lines in the case of sub-irrigation. Because sub-irrigation depends on an upward flow of water, there would be a danger that salts moving up close to the surface would inhibit seed germination. Fortunately, the inhibition did not occur and no retardation of plant growth was observed even when the content of salts in the water was 1100 ppm (5).

Use of saline water for irrigation.

Trials in Israel using saline water for irrigation with trickle systems were highly positive. The saline water had an electrical conductivity of 3000 micromhos/cm. The saline water used with sprinkler irrigation significantly reduced yields, especially on tomatoes. With trickle irrigation, the yields were about the same for both poor and good quality water (10).

Several trials were conducted in California. Edlin (5) mentions that subsurface irrigated crops were raised in Arizona on soil having 6000 ppm of dissolved salts with the irrigation water having 1800 ppm. A white salt crust appeared on the surface. Adequate leaching was required to remove the salts from the surface and the root zone (5).

Voth (5) reported irrigation of strawberries with water containing 1100 ppm salts. On the trickle irrigated beds the

electrical conductivity decreased while on the furrow irrigated beds the conductivity increased. The measurements were made on samples from zero to six inches depth (5).

De Remer (5) reported on a research study using saline water for trickle irrigation. The research was undertaken by the U.S. Salinity Laboratory at Riverside, California. The results showed a large growth difference between trickle irrigated peppers and peppers irrigated with sprinklers and furrows. The trickle irrigated peppers responded better than those irrigated by other methods. Unfortunately, no quantitative data was tabulated.

Another possible measurement of salts is by measuring the chloride content of the leaves. In Israel, Goldberg (10) carried out a number of tests with several different types of plants. The results showed that plants under trickle irrigation contained considerably less chlorides (about one half) than plants irrigated by furrows or sprinklers. The plants tested were white beans, musk melons, peppers and grapevines.

From another trial with water of different salinity levels the following conclusions were made:

1. Water containing 2400 ppm of dissolved salts causes a strong reduction in growth and yield even with trickle irrigation.
2. Water with 1600 ppm of dissolved salts can be used but the soil needs leaching between growing seasons.
3. Plant growth, dry matter production and leaf water potentials decreased with increasing electrolyte concentration of the irrigation water.

4. Lower salinity levels appeared directly beneath and between the double rows with 1600 ppm water.

5. Considerably higher yields occurred on trickle irrigated plots than on surface irrigated plots using 1600 ppm water (23).

Hydraulic Design of Trickle Irrigation.

Trickle irrigation system design and the hydraulic solution for the system is quite complicated. A designer must first deal with the soil characteristics. Soil is actually a complex of minerals, organic matter, water and air which varies greatly in the field. Another problem is three-dimensional flow and dynamic conditions. The problem is difficult to analyze theoretically but the analytical approach is possible (31).

Proper design must fulfill three basic requirements:

1. The flow of water must be sufficiently high so that the system will be capable of supplying the daily evapotranspiration requirements of the crop.
2. The uniformity of water distribution must be acceptable.
3. The system must be economical.

Values for evapotranspiration can be obtained from average values which are known for a particular area. The average should not be taken for the entire season because evapotranspiration during the season varies considerably. A division for spring, midsummer and fall evapotranspiration should be made. The average value used for design purposes should therefore be the highest value.

The economics of the system should be carefully analysed and eventually several alternatives studied in order that the best one is chosen (28).

Flow in trickle irrigation pipes can be solved as general manifold flow. The only difference in the solution is that some factors are so insignificant that they can be neglected. The expressions and equations of flow can therefore be simplified and approximate solutions for longitudinal velocity and lateral outflow distributions can be computed. Zsak (32) developed equations based on the principle of continuity and the energy balance equation. The design criteria deals with a subsurface lateral using special plastic valves. The procedure can be adapted for the design of surface laterals but special attention must be paid to different types of emitter construction.

Zetche-Newman solution for lateral design.

Zetche and Newman (31) theoretically computed the length of lateral, drop of piezometric head and discharge by using an IBM 360 computer. Their interest was concerned with the design of a lateral for subsurface irrigation.

Design of such a lateral involves analysis and study of changes in pressure head, size of pipes and spacing of orifices. Changes in pressure head are due to head loss from friction, head gain from velocity transformation, head loss from orifice roughness and turbulence, and head change due to pipe elevation change.

Calculation of friction loss depends on flow. Because the flow varies from turbulent (at the head of lateral) to laminar (at the end

of lateral) the calculation is quite difficult. The Darcy formula for head loss by friction is:

$$H = f \frac{L}{D} \frac{v^2}{2g}$$

where: f is the friction factor,

L is the length of the pipe in ft,

v is the mean velocity of flow in ft/sec,

D is the diameter of the pipe in ft, and

g is the acceleration due to gravity in ft/sec^2.

The Moody diagram for smooth pipes can be used to determine the friction factor for turbulent flow. Zetche and Newman measured manifolds and included the values on the Moody diagram for the transition zone. Laminar flow can be considered when the Reynolds number, Re, is less than 1000. For values more than Re = 200,000, the calculations are discontinued. For laminar flow, the friction factor f is computed according to the formula:

$$f = \frac{64.4}{Re}$$

The increase in head due to velocity changes across a branch or orifice was studied by McNown (20). The data presented was obtained and used for his calculations. Actually, an interpolation from the curve can be made. This curve expresses the ratio of orifice flow to pipe flow, $\frac{Q\ \text{orifice}}{Q\ \text{pipe}}$, as a function of the ratio of head change to velocity head, $\frac{h}{v^2/2g}$.

The head loss across an orifice due to friction is difficult to measure. The head loss depends upon the shape of the orifice and

the internal flow characteristics. Generally, this head loss can be considered to be negligible.

Calculation of outflow for each orifice with the respective pressure head can be computed from the equation:

$$Q = CA\sqrt{2gh}$$

where: Q is the flow rate in ft^3/sec,

CA is the product of orifice area and coefficient in ft^2,

g is the acceleration due to gravity in ft/sec^2, and

h is the pressure head in ft.

A computer program was written to compute the length, the discharge distribution and the pressure distribution. For each orifice, the head was computed from the equation:

$$H = H_1 + H_{loss} - H_{elev} - H_{gain}$$

where: H is the computed head,

H_1 is the head at the previous orifice which must be chosen for the start of the computation,

H_{loss} is the head loss due to friction in the orifice,

H_{elev} is the head loss or head gain due to elevation,

and H_{gain} is the velocity transformation head change.

The first head value chosen is actually the head which is required at the end of the lateral. The head loss values decrease and when they reach zero,the computer stops because the beginning of the lateral has been reached. The discharge rate is computed as well and when the ratio

of discharge from the last orifice and the orifice just computed is less than 50%, the computer stops. This is a check that the discharge is uniform.

The printout includes: length of lateral, orifice flow ratio, pressure head, pipe flow, orifice flow and elevation. All of these variables are printed out in pre-selected intervals (31).

I-pai Wu and Gitlin solution for lateral design.

The calculation is based on uniform flow from all emitters and a constant emitter spacing. The "Micro-tube" emitters in this system are plastic tubes 0.02 - 0.03 in. in diameter. The discharge depends on the length of microtube. For computations of the pressure distribution along the lateral, the average discharge from three or more sections of lateral is used. The basic equation for the calculation is the dynamic equation of spatially varied flow with decreasing discharge in a drop irrigation line and can be expressed as:

$$\frac{dh}{dL} = S_o - S_f \tag{1}$$

where: S_o is the slope of the drip line,

S_f is the friction or hydraulic grade line slope,

and $\frac{dh}{dL}$ is the change of pressure with respect to the length or the slope of pressure gradient line.

S_o can be assumed zero for zero slope of the field so that

$$\frac{dh}{dL} = -S_f \tag{2}$$

$$f = \frac{0.3146}{Re^{0.25}} \quad \text{for } 3{,}000 < Re \leq 100{,}000 \tag{3}$$

When substituting equation (3) into equation (2) then

$$\frac{dh}{dL} = -kQ^{1.75} \tag{4}$$

where:

$$k = \frac{2.53 \cdot \nu^{0.25} \cdot A^{0.25}}{g \cdot \pi^2 \cdot D^{5.25}} \tag{5}$$

Equation (4) can be used to determine the energy drop between the given length, dL. If dL is fixed as a given length interval, ΔL, and considered as a constant, then equation (4) can be solved numerically.

$$\Delta h_p = -kQ_p^{1.75} \cdot \Delta L \tag{6}$$

where Δh_p is the friction drop in the p-th section of lateral.

The total friction drop ΔH will be:

$$\Delta H = \sum_{1}^{n} \Delta h_p \tag{7}$$

The meaning of the symbols is:

f is the friction factor expressed in the Blasius empirical formula-equation (3),

k is the constant,

ν is the dynamic viscosity in ft^2/sec,

A is the area of pipe cross-section in ft^2,

g is the gravitational acceleration in ft/sec^2,

D is the diameter of pipe in ft,

L is the pipe length in ft,

Q is the total discharge in gals/min,

and Q_p is the total discharge in the p-th section of pipe.

By using the average discharge for the computation, an error is

committed. The pressure gradient line is an exponential type of curve. Division of the lateral into several sections and using the average discharge from every section is recommended. Thus, the shape of the exponential curve can be approached. If the lateral is divided into three or more sections the error is about 2%.

The next step in the calculation is determination of the size and length of emitters (microtubes) in order to obtain a uniform discharge. A computer program can be used for all these calculations.

Certain errors must be taken into consideration when using the above mentioned procedure. Laboratory experiments are needed to determine the exact relationship between the friction coefficient and the Reynolds number (17).

METHODS AND PROCEDURE

General.

A trickle irrigation project was set up in 1972 at the Alberta Horticultural Research Center at Brooks, Alberta. The project was cooperative between the Research Center and the Irrigation Division of the Alberta Department of Agriculture. The plot area was divided into a furrow and a trickle irrigated section so a comparison of the two methods could be made. The project was originally scheduled for three years. The objectives of the project were:

1. To determine if trickle irrigation is a feasible method for some specialized crops grown in Alberta,
2. To study soil-water-plant relationships for the specialized crops irrigated with the trickle systems.

In 1973 the trials were expanded to include four different systems for four different crops. In addition, a cooperative project was set up, whereby the University of Alberta purchased another four systems. In total, eight systems were then used for the hydraulic and operational studies.

Description of the Plot.

Plot 10B at the Alberta Horticultural Research Center was the location for the study. The selected area was a rectangular shape, 420 ft long by 200 ft wide. For the Alberta Government systems, four crops were planted with three rows of each crop. The crops were strawberries, tomatoes, cucumbers and carrots. Four of the systems

were trickle systems while the fifth system was a furrow irrigated control system.

For the other four trickle systems used,only tomatoes were planted and each system had five rows. The spacing of rows and therefore the laterals for the crops were as follows: strawberries and tomatoes - 4 ft, cucumbers - 6 ft, and carrots - 3 ft on raised beds. The spacing between emitters was 2 ft. Buffer zones 10 ft wide were left between each crop and each system. The assumption was that the buffer zone and the three-row layout would be adequate so that the center row would be relatively free of border effects and would be representative of average field conditions. Figure 1 shows the plot layout. Also shown is the test lateral where the pressure and discharge measurements were taken. The names of systems shown and subsequently used in the text, are the brand names.

The Government systems were: Chapin Double Wall, Rinko, Salco and Anjac Bi-Wall. The University of Alberta systems were: Submatic, Miniflow, Viaflo and Uniflow.

System Components.

The trickle irrigation system had three main parts:

1. Head,
2. Main line,
3. Lateral lines with drippers (emitters).

The head consisted of: a settling tank, a pump, filters with pressure gauges, a water meter, a pressure regulator, and a fertilizer tank. The function of the head was to supply clean water at the desired system

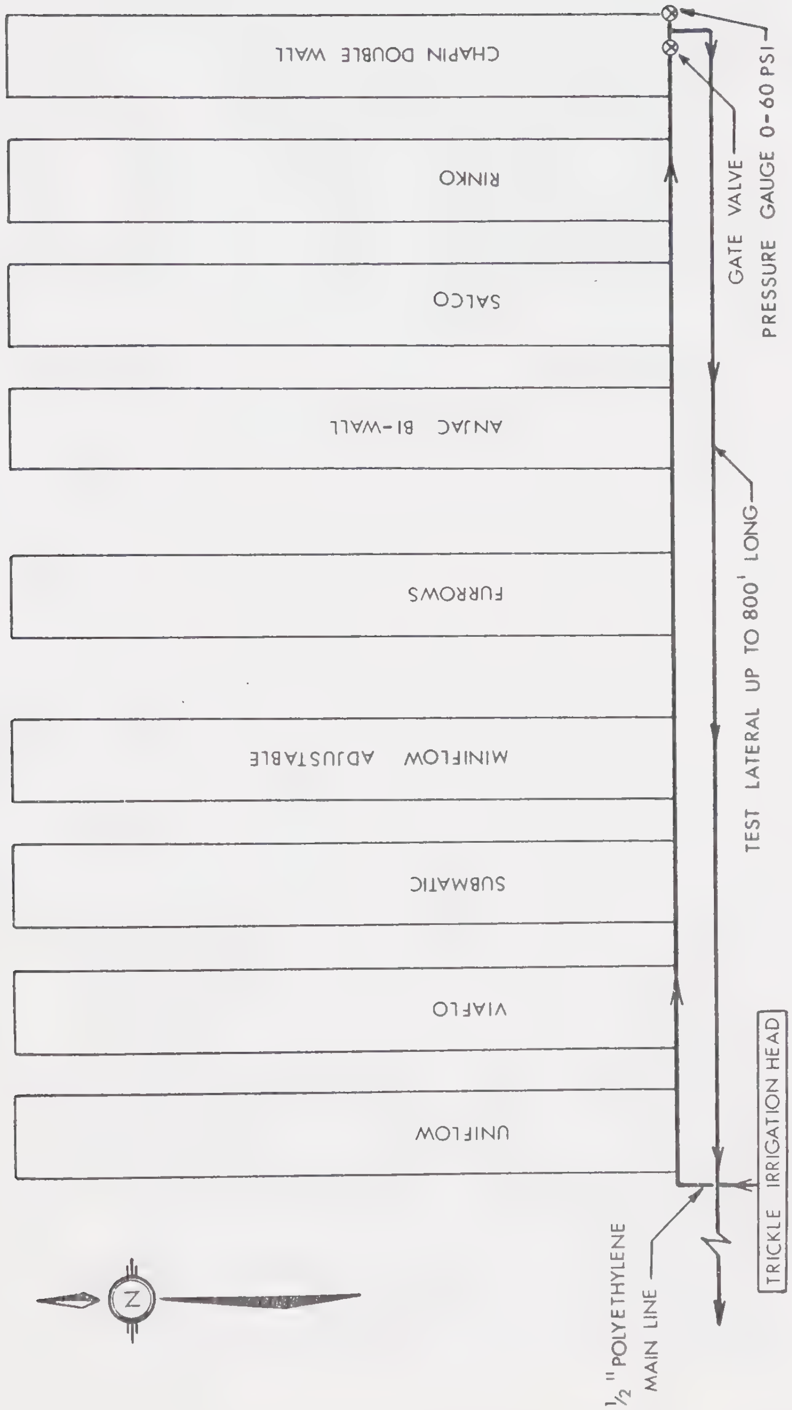


Figure 1. General Plot Layout.

pressure and to inject water soluble fertilizer into the main line. Figures 2, 3, 4 and 5 show all parts of the head except the fertilizer tank. The sand filters are parallel connected and contain manganese sand. Sometimes it was necessary to add a finer filter after the sand filters (Fig 4). The pressure regulator maintains a uniform pressure in the system and helps to maintain a uniform discharge.

The main line was 1 1/2 in. polyethylene pipe. All junctions for the laterals were plastic "Tee's". The water for each crop within each system was regulated by a gate valve. A pressure gauge was located at the end of the main line to monitor the pressure losses in this line.

The laterals were polyethylene and ranged in size from 1/2 to 3/4 in. in diameter. The emitters or drippers were equally spaced at 2 ft. Eight different types of laterals were used.

Description of trickle laterals and emitters.

The Chapin Double Wall is a six-mil polyethylene hose-within-a-hose. The orifices are spaced 32 in. apart in the inner hose and 8 in. apart in the outer hose. The diameter of the orifices is 0.025 in. The inner diameter of the hose is 0.59 in. (Fig 6).

The Rinko laterals are made of semi-rigid polyethylene pipe, 3/4 in. in diameter, with an in-line barbed emitter spaced every 2 ft. The laterals are factory assembled. The emitter is made of polypropylene plastic. Water is forced along a continuously reversing path (a labyrinth) for a distance of 8 ft before dripping out of the emitter (Fig 7) (27).

The Salco system consists of 1/2 in. diameter polyethylene hose with "adjustable" type emitters spaced every 2 ft (Fig 8 and 9). The hose is cut, and the emitter is glued into each end. This type was

Figure 2. Settling Tank.

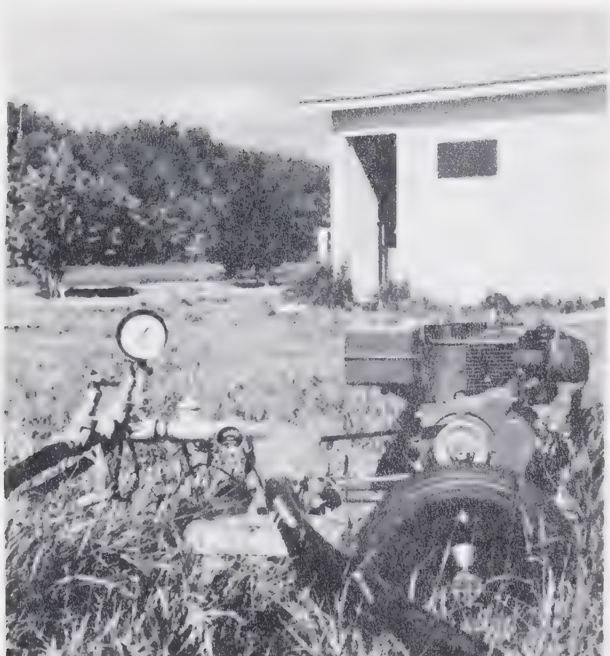


Figure 3. 30 GPM Pump.

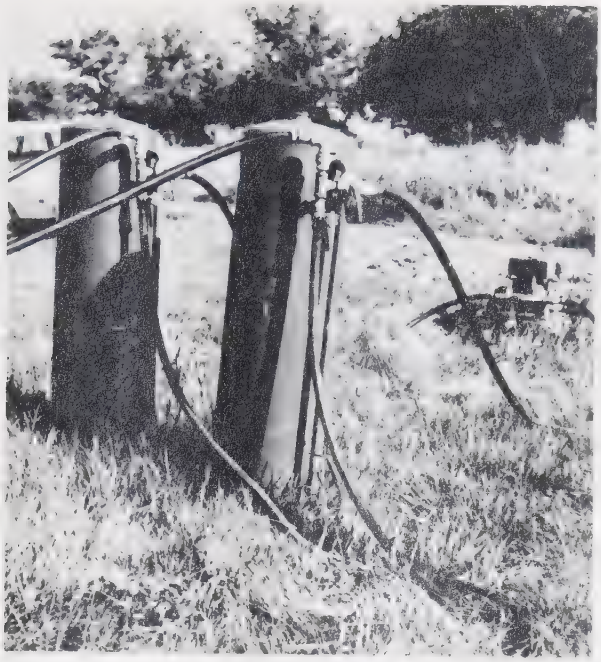


Figure 4. Sand Filters.

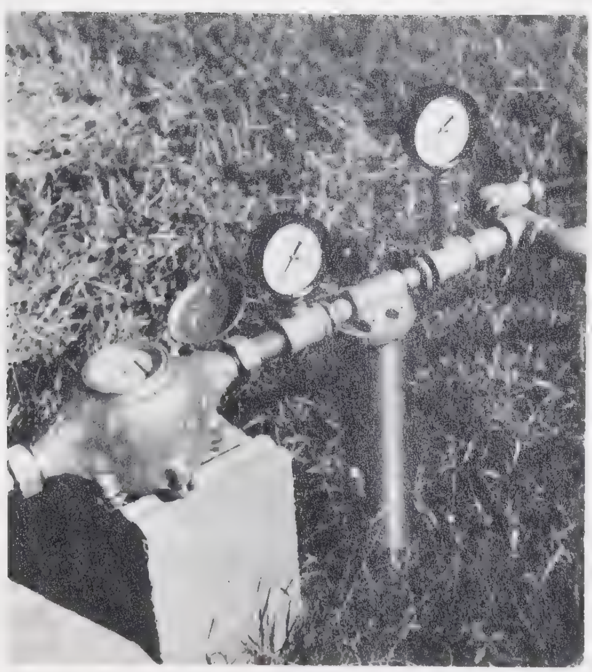


Figure 5. Felt Filter and Water Meter.

previously used for the 1972 trials.

The Anjac Bi-Wall (Fig 10) is a 16 mil seamless polyethylene tubing. The feed holes in the interior tube are spaced at 96 in. and the emission holes in the outer wall are spaced at 24 in. Both holes are bored with a laser beam and are 0.019 in. in diameter. The internal diameter is 1/2 in.

The Miniflow Adjustable consists of a 1/2 in. polyethylene lateral. The emitter has two parts with male and female ends. The male part has a piercing point to penetrate and lock into the plastic line while the other end is threaded. The female part is threaded on one end and has an arrow-grip on the other end. Between these two parts (male and female), a rubber disc with a control orifice is inserted. The discharge depends on the compression of the rubber disc (Fig 11).

The Submatic uses a polyethylene line for the lateral. Small plastic emitters were inserted at a two-foot spacing. Every emitter has a piercing end which penetrates the lateral (Fig 12). Special pliers are needed for inserting the emitter.

DuPont Viaflo is a paper-like 1/2 in. diameter porous polyethylene tubing. With the application of water at a low pressure, the tubing inflates and allows the porous walls to sweat or drip along the entire length of the lateral (Fig 13).

The Uniflow are self-cleaning emitters. The construction is quite complicated. As with the Salco system, the emitters are inserted and glued into the cut end of the hose at 2 ft intervals (Fig 14).

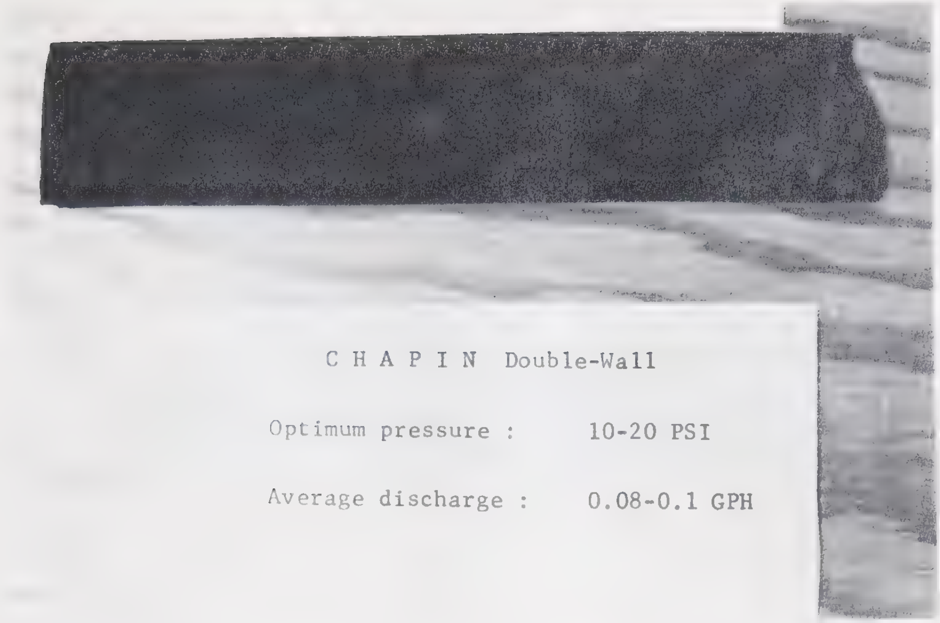


Figure 6. Chapin Double Wall.

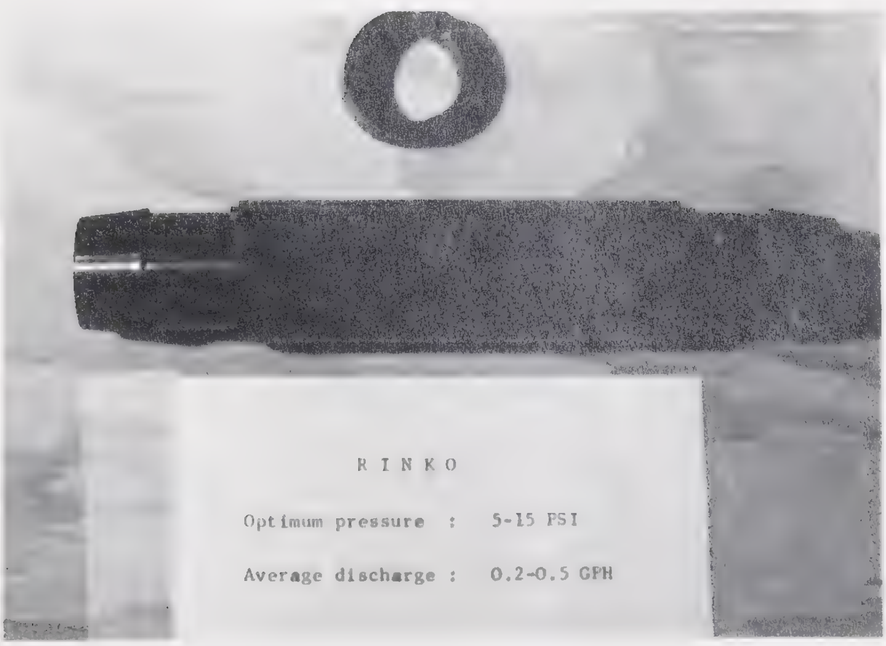


Figure 7. Rinko.

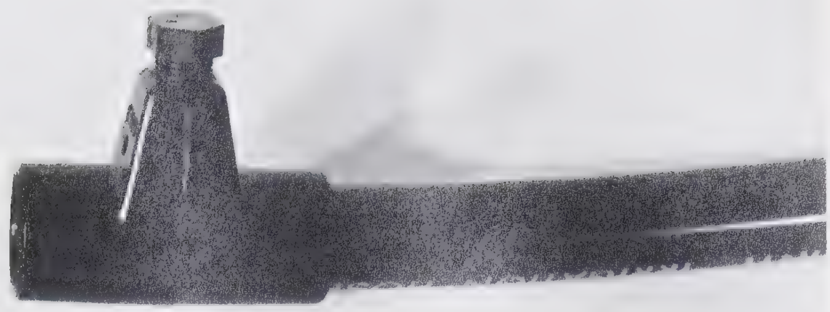


Figure 8. Salco.

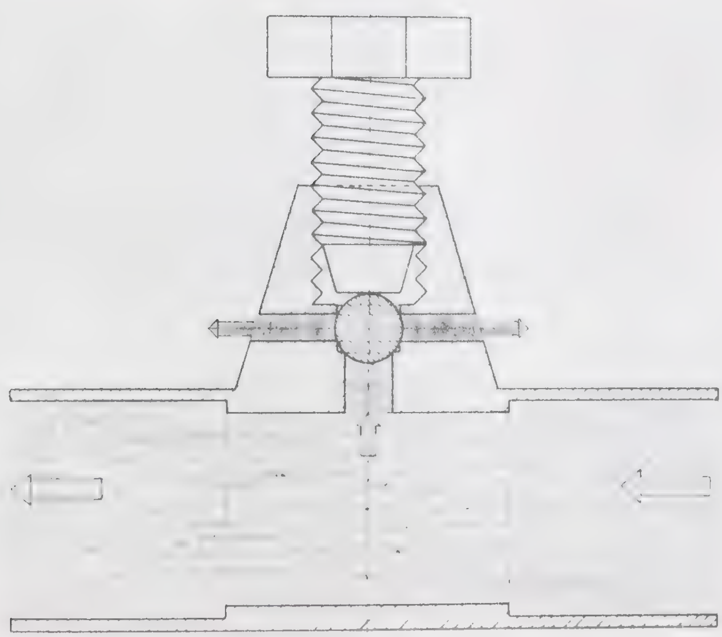


Figure 9. Cross-section of Salco.

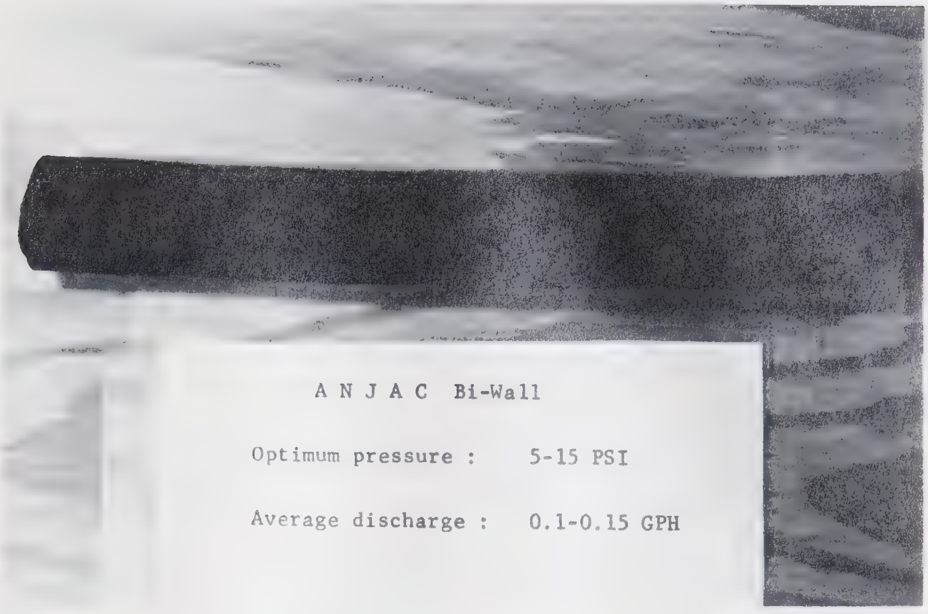


Figure 10. Anjac Bi-Wall.

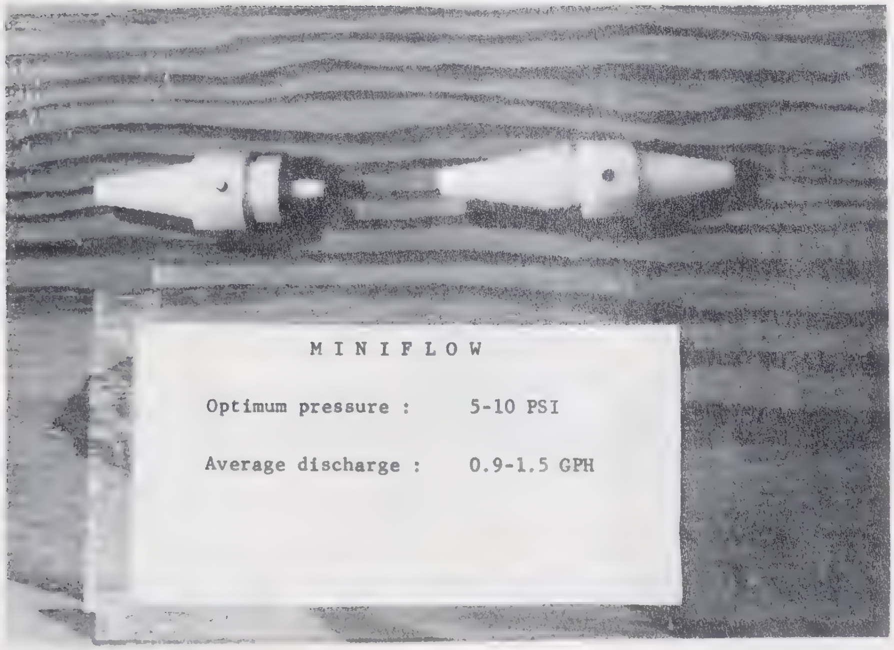


Figure 11. Miniflow Adjustable.

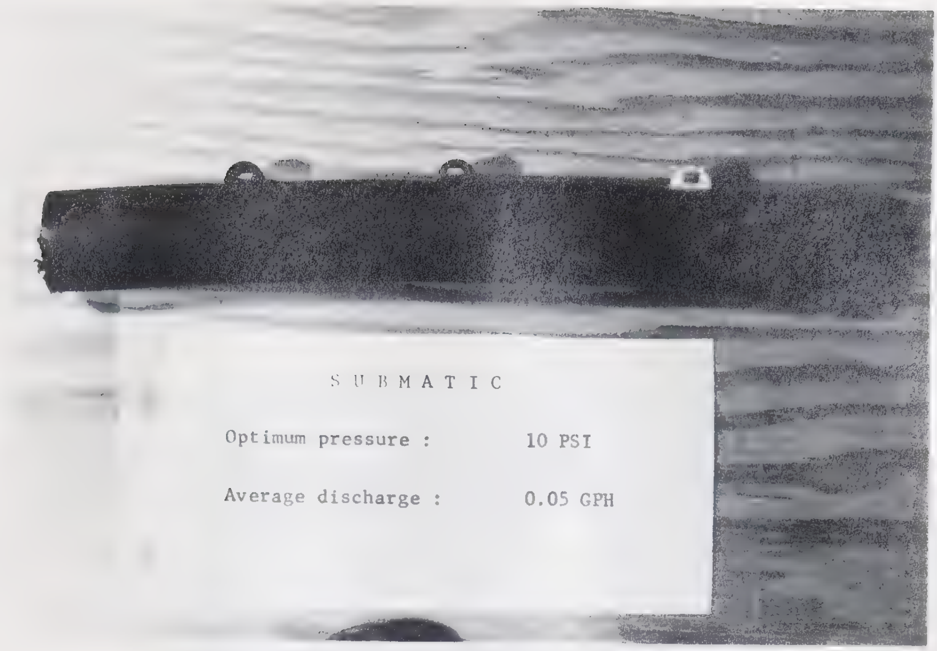


Figure 12. Submatic.

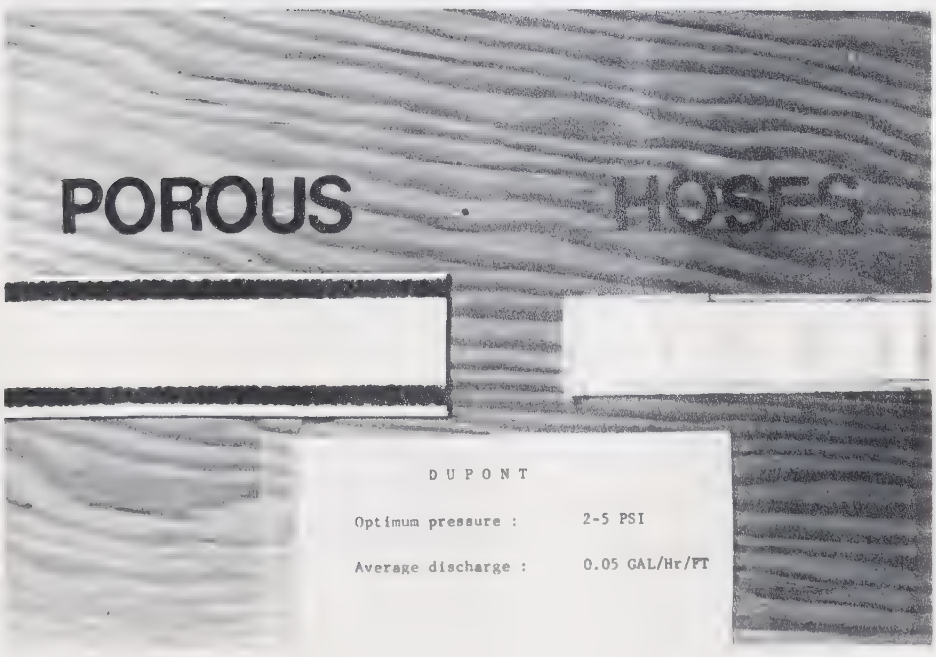


Figure 13. Viaflo.

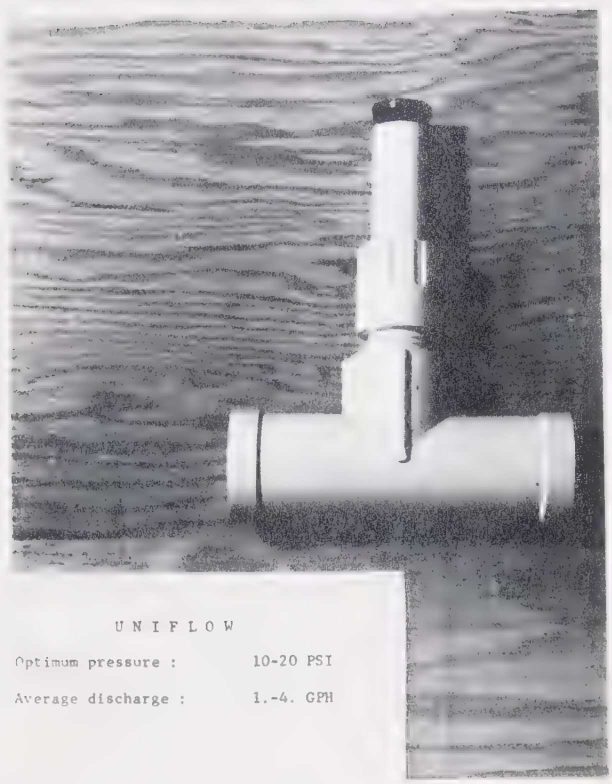


Figure 14. Uniflow.

Installation and Procedure.

Installation of the head, main lines and the laterals was finished by May 24, 1973 with the exception of the Rinko laterals (which were delivered later). The operation of the laterals was started on this date on a rotation basis. Irrigation was started on the east end (Chapin Double Wall) and finished on the west end (Uniflow system). The entire cycle took approximately one week. When necessary, two systems could operate simultaneously. The operating pressure for the plot area throughout the season was approximately 5 psi.

Water for furrow irrigation was supplied through a 6 in. diameter gated pipe. The amount of water applied was measured with a propeller water meter. The runoff was measured by using an H-flume equipped with an automatic recorder. The east end of the main line was equipped with a gate valve and adaptor, so that later on, the 800 ft test lateral could be connected for pressure and discharge measurements (Fig 1).

Pressure and discharge measurements.

All systems tested had been previously used for field irrigation. This was done to avoid the use of new equipment and in this way to approach a true field condition. The lateral to be tested was removed from the plot and laid out along the main line. The maximum length of test lateral was 800 ft. Each lateral was tested at four different mainline pressures; the Chapin Double Wall was operated at 5, 10, 20 and 30 psi and the other systems at 5, 10, 15 and 20 psi. The exception was the Viaflo porous hose which was tested at 5, 10 and 15 psi only.

Since the lateral pressure distribution was expected to be a logarithmic function, the measuring points were set at 20 ft intervals for the first 200 ft and at 50 ft intervals for the remainder of the length. A simple water manometer was used to measure pressures up to 6 psi and a 0 - 60 psi pressure gauge was used for those pressures over 6 psi. For discharge readings, a graduated cylinder and a stop-watch were used. Each pressure and discharge reading was taken twice. The temperature of water from the first emitter was recorded. All measuring points along the line were accurately surveyed. The measuring started the middle of July 1973 and continued for four weeks.

The results from the pressure and discharge readings, with their averages, are summarized in the Appendix, tables 1a - 17a. On the following pages, these results are plotted as graphs (Fig 15 - 47) as well as the best fit curves. These curves were computed to obtain the relationship between the length of lateral, pressure and discharge for design purposes (see section on design of trickle irrigation systems).

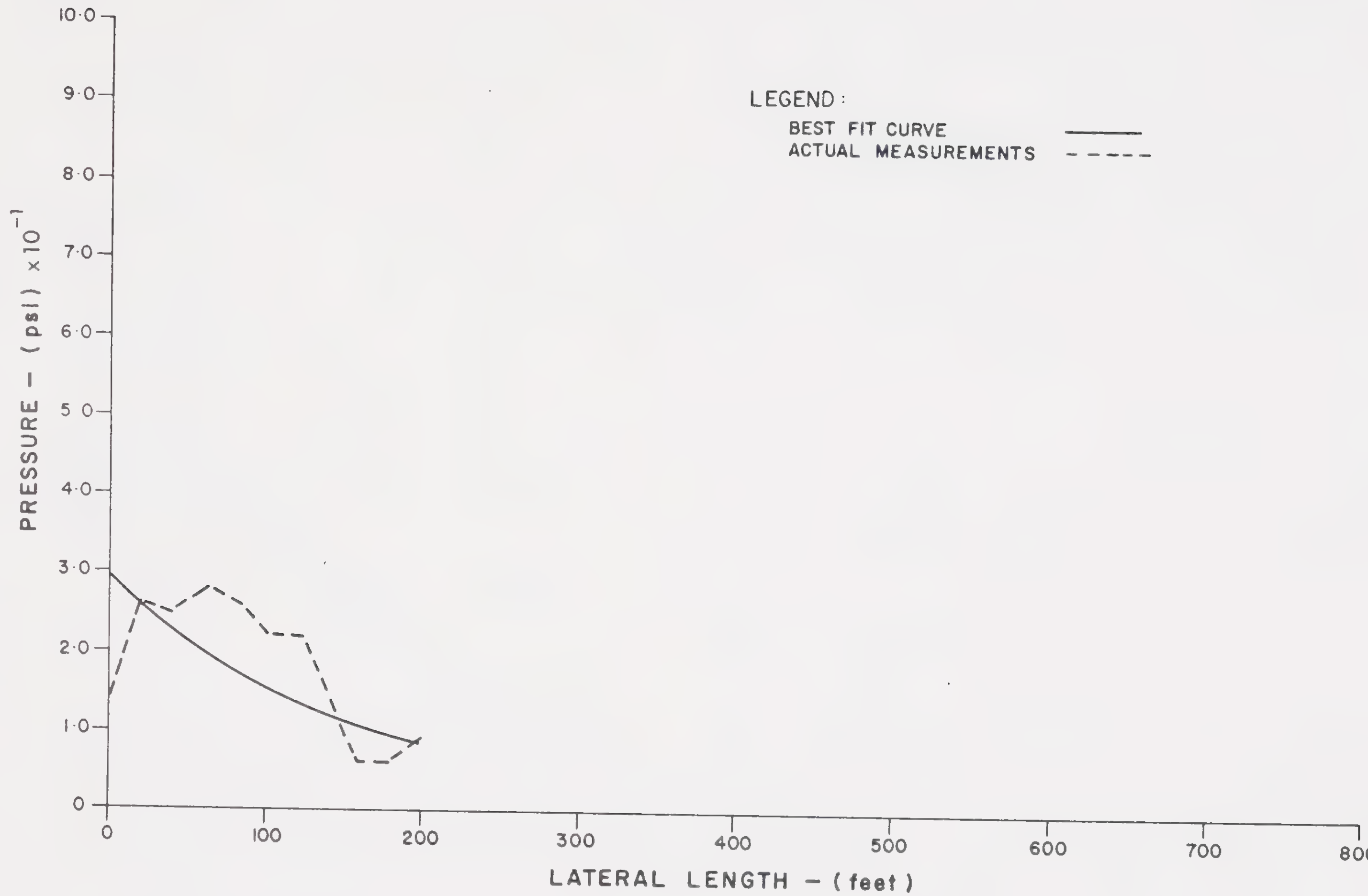


Figure 15. Pressure vs. Location Curve for Chapin Double Wall at 5 PSI.

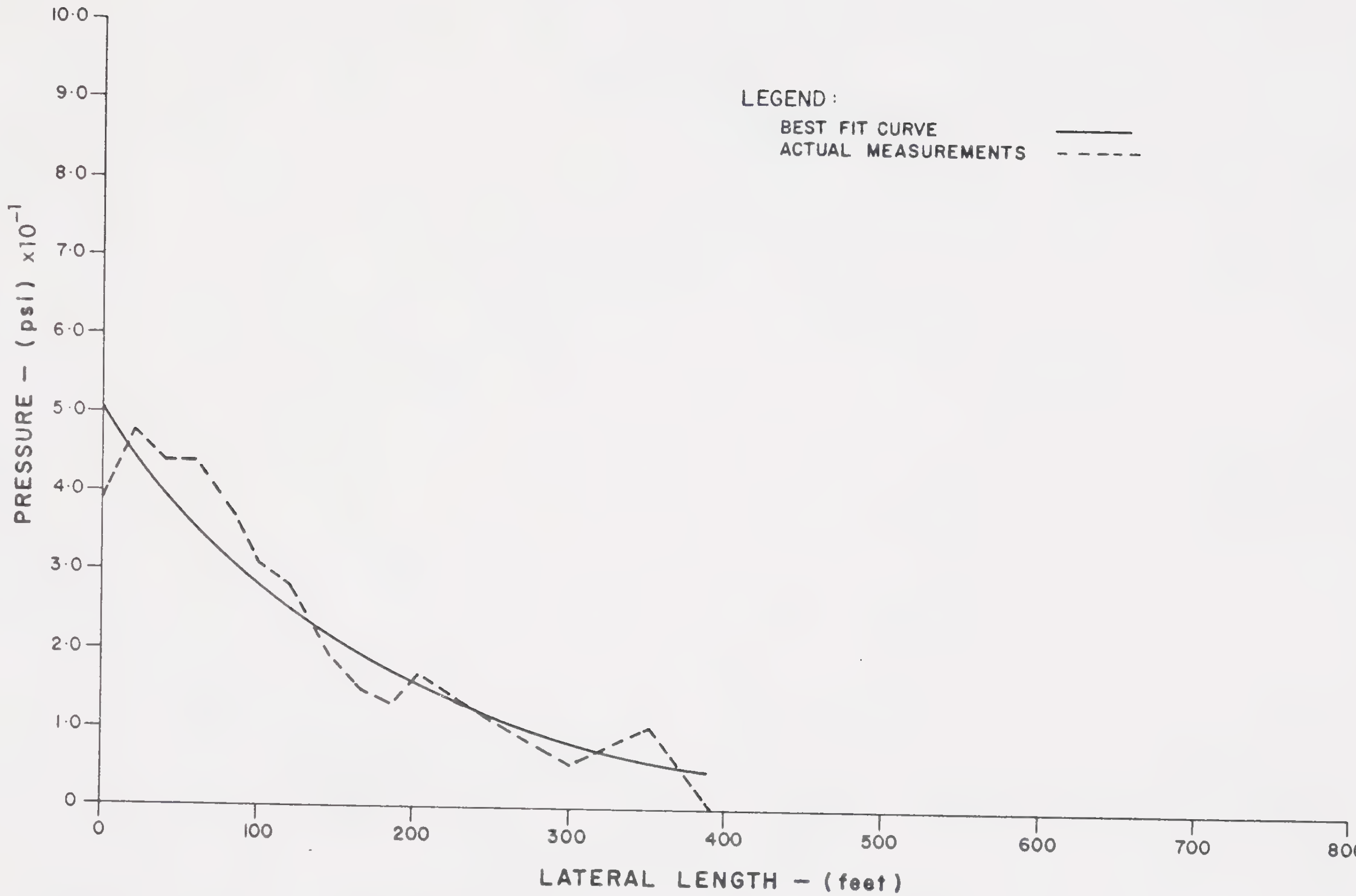


Figure 16. Pressure vs. Location Curve for Chapin Double Wall at 10 PSI.

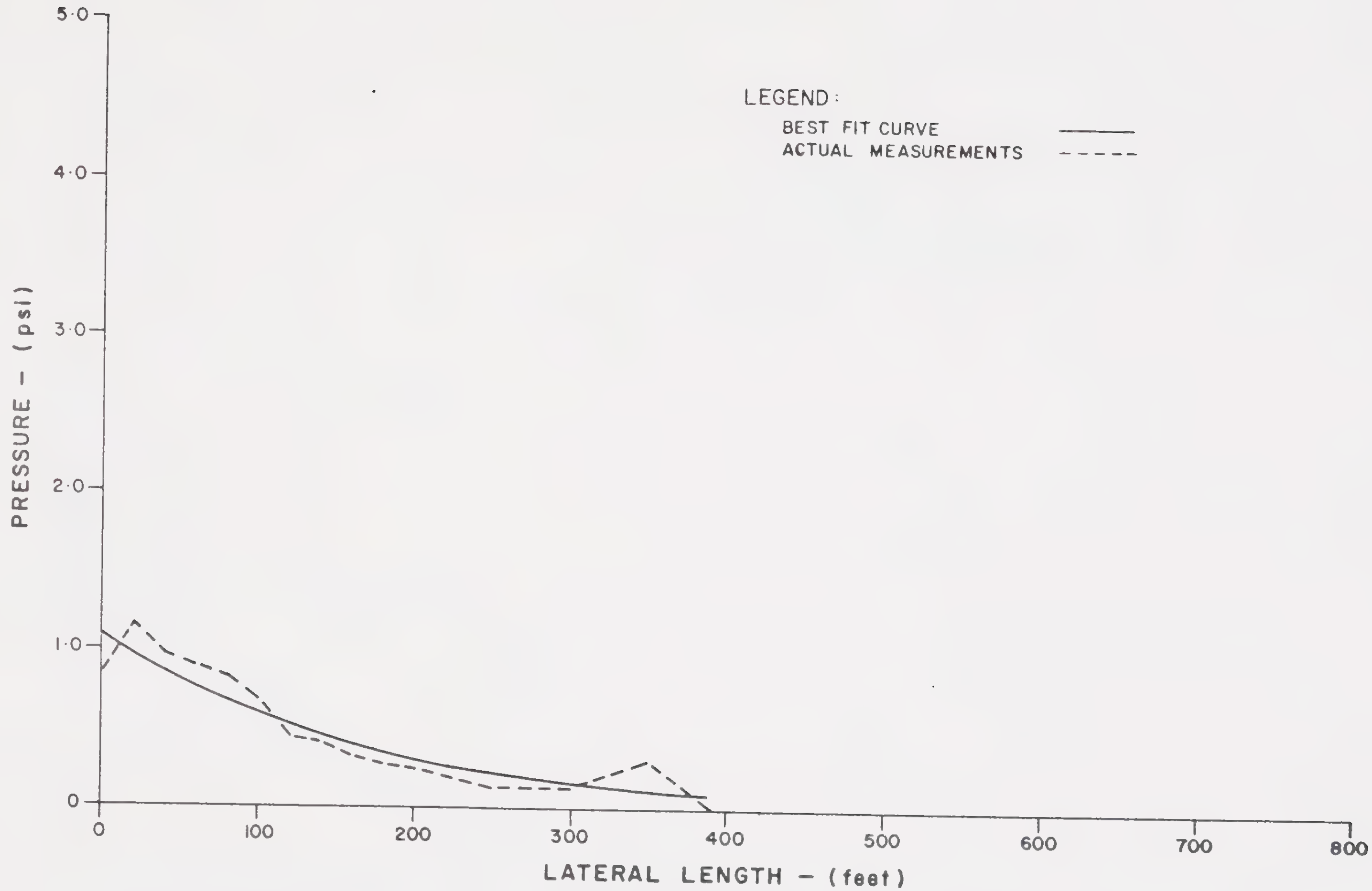


Figure 17. Pressure vs. Location Curve for Chapin Double Wall at 20 PSI.

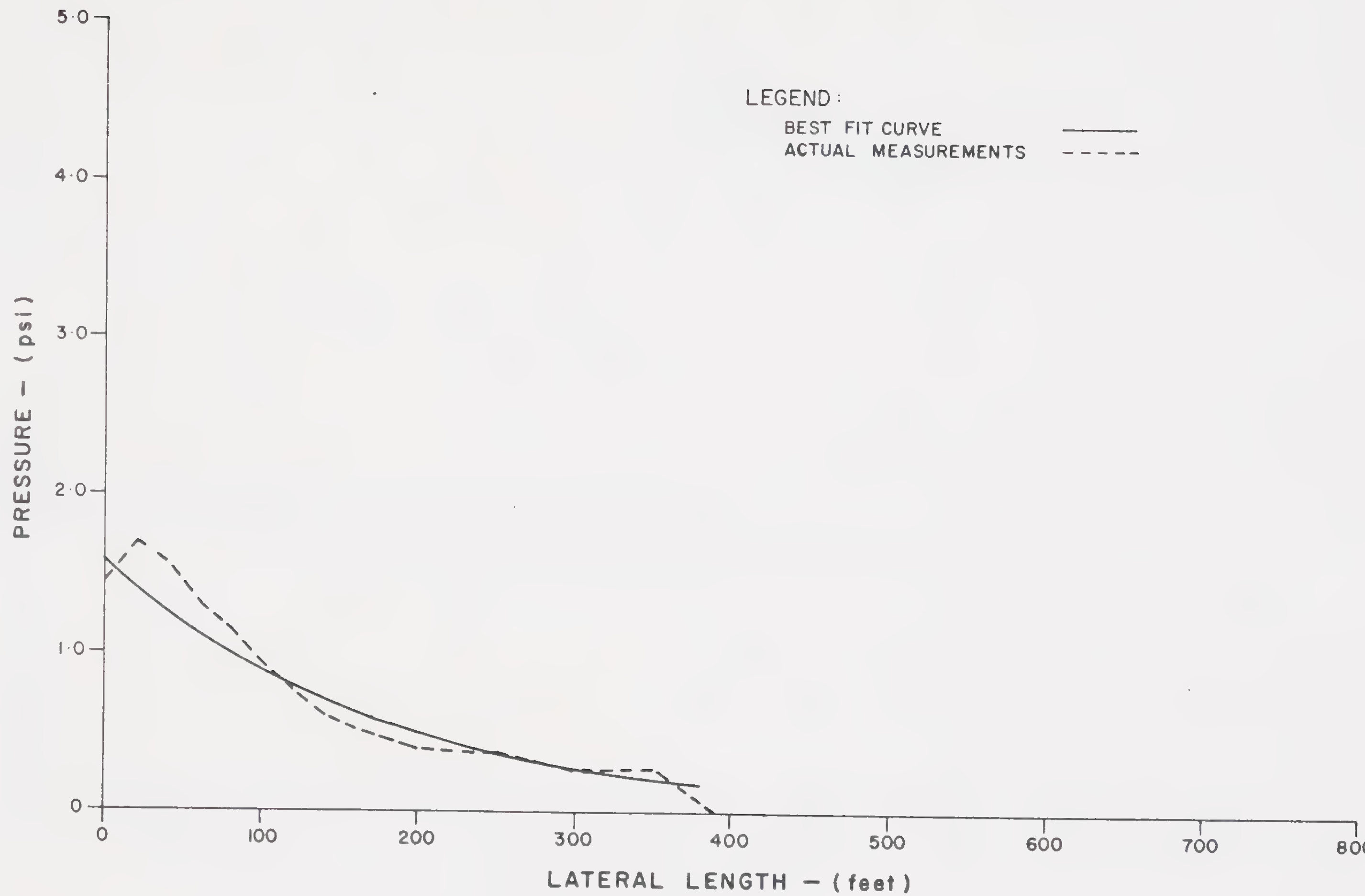


Figure 18. Pressure vs. Location Curve for Chapin Double Wall at 30 PSI.

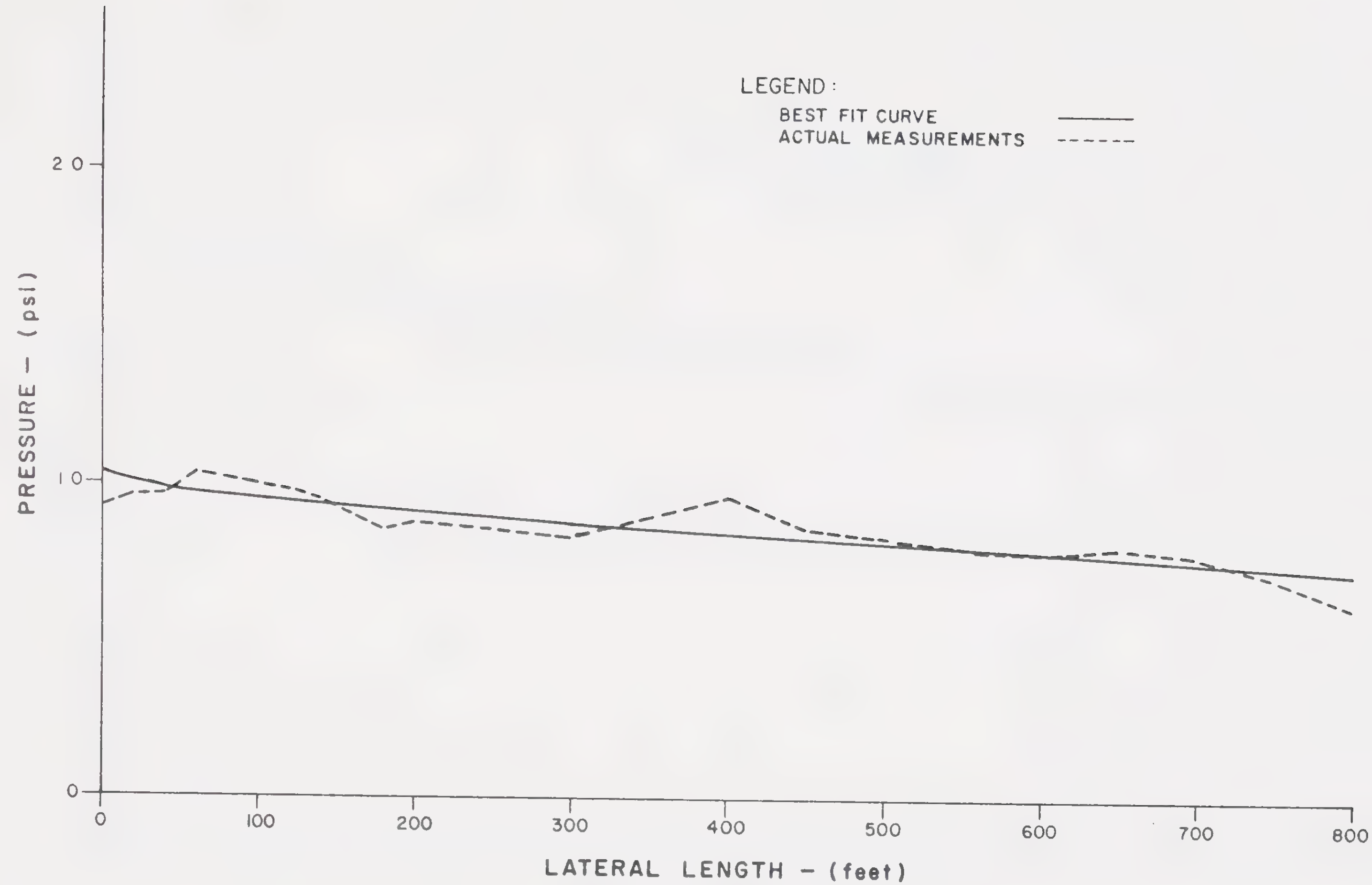


Figure 19. Pressure vs. Location Curve for Anjac Pi-Wall at 5 PSI.

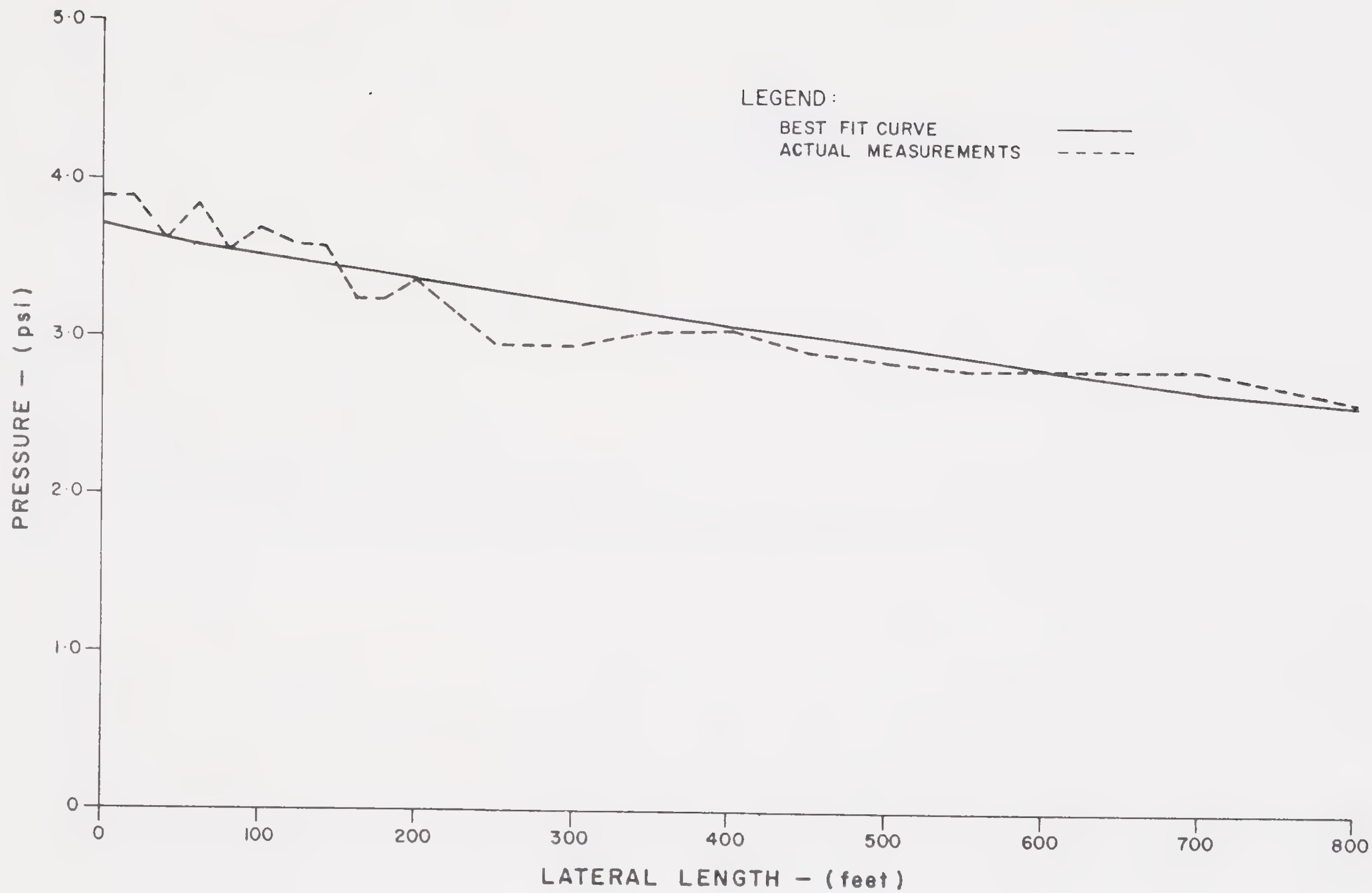


Figure 20. Pressure vs. Location Curve for Anjac Bi-Wall at 10 PSI.

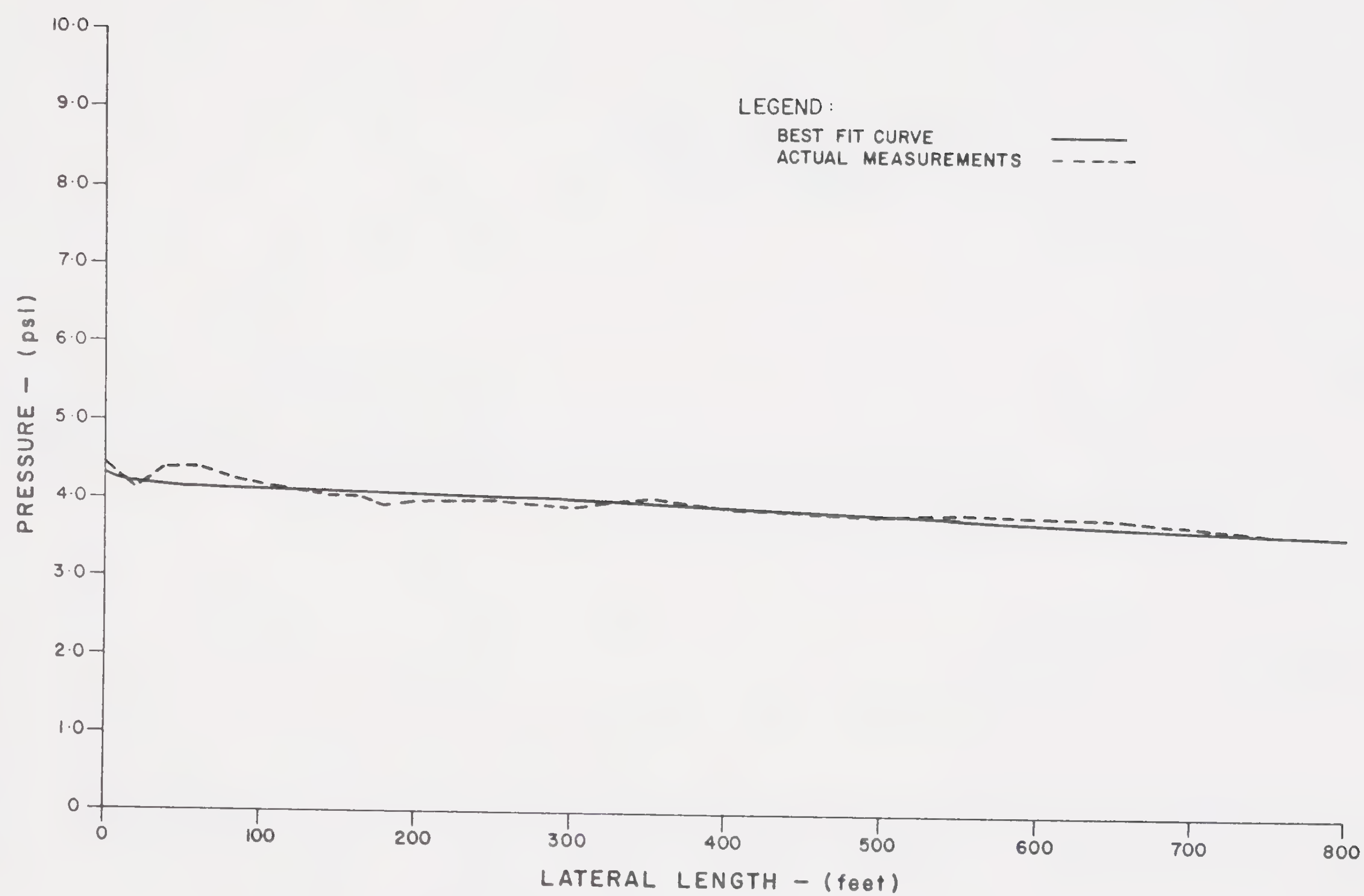


Figure 21. Pressure vs. Location Curve for Anjac Bi-Wall at 15 PSI.

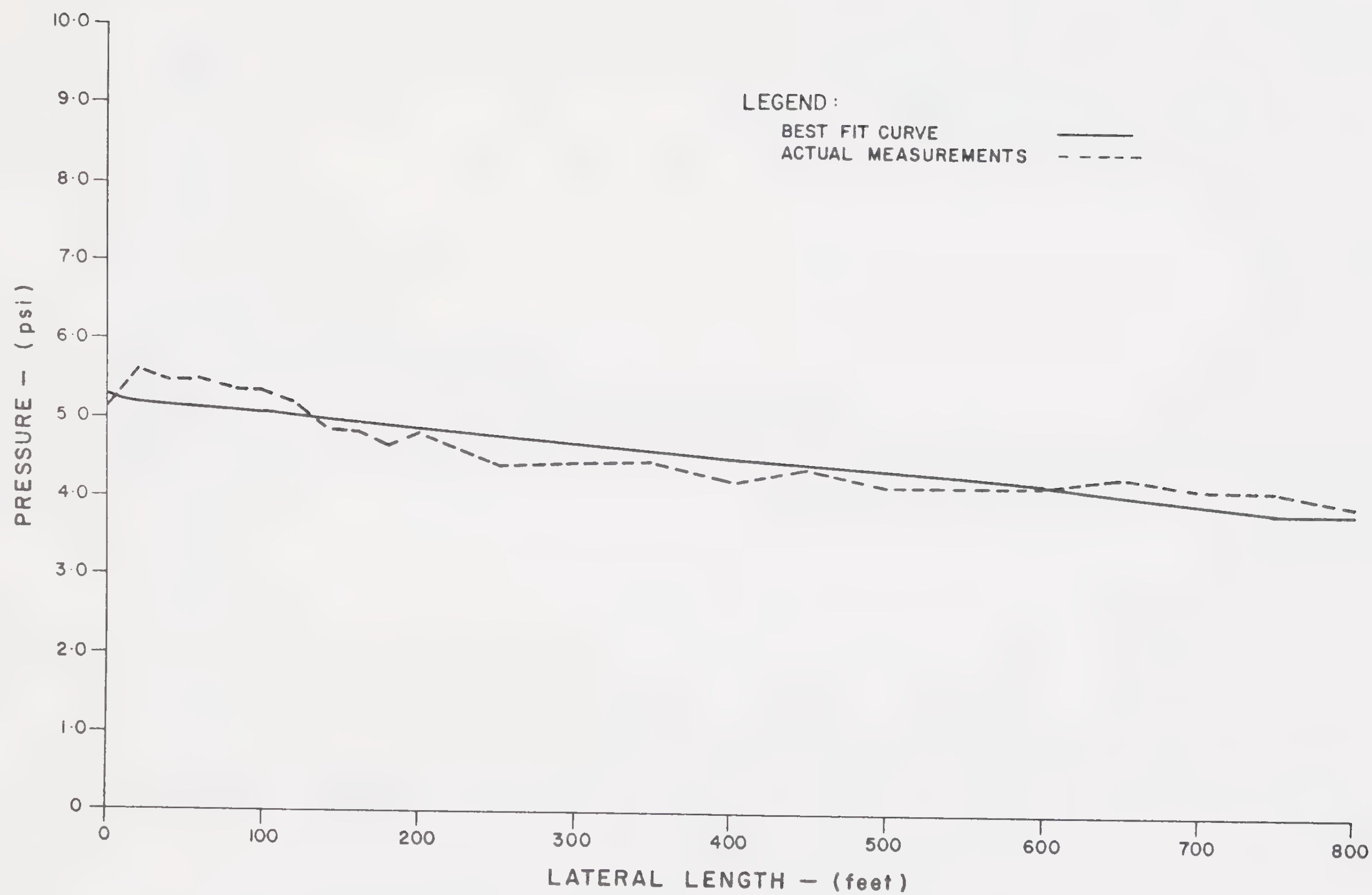


Figure 22. Pressure vs. Location Curve for Anjac Bi-Wall at 20 PSI.

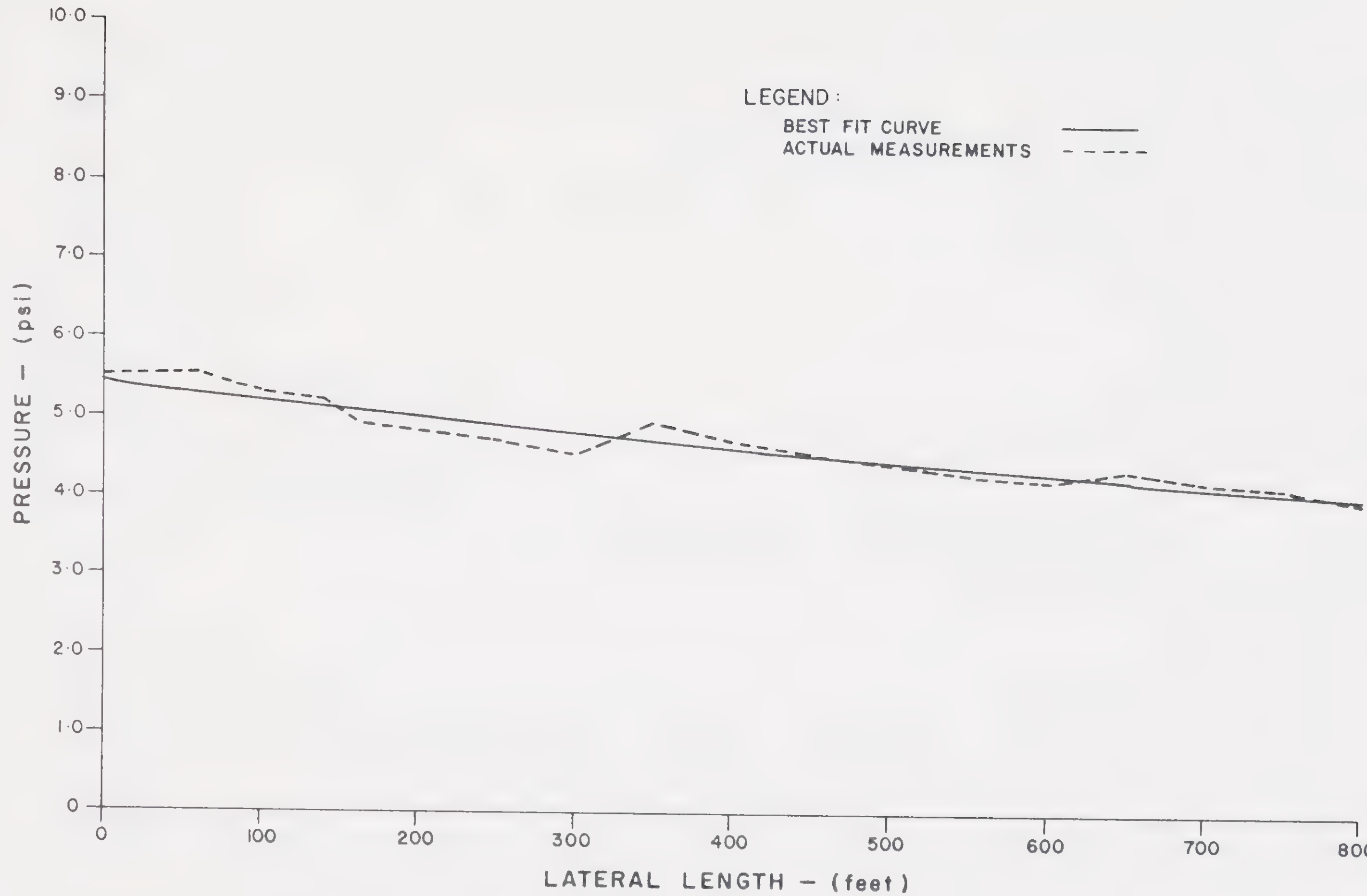


Figure 23. Pressure vs. Location Curve for Rinko at 5 PSI.

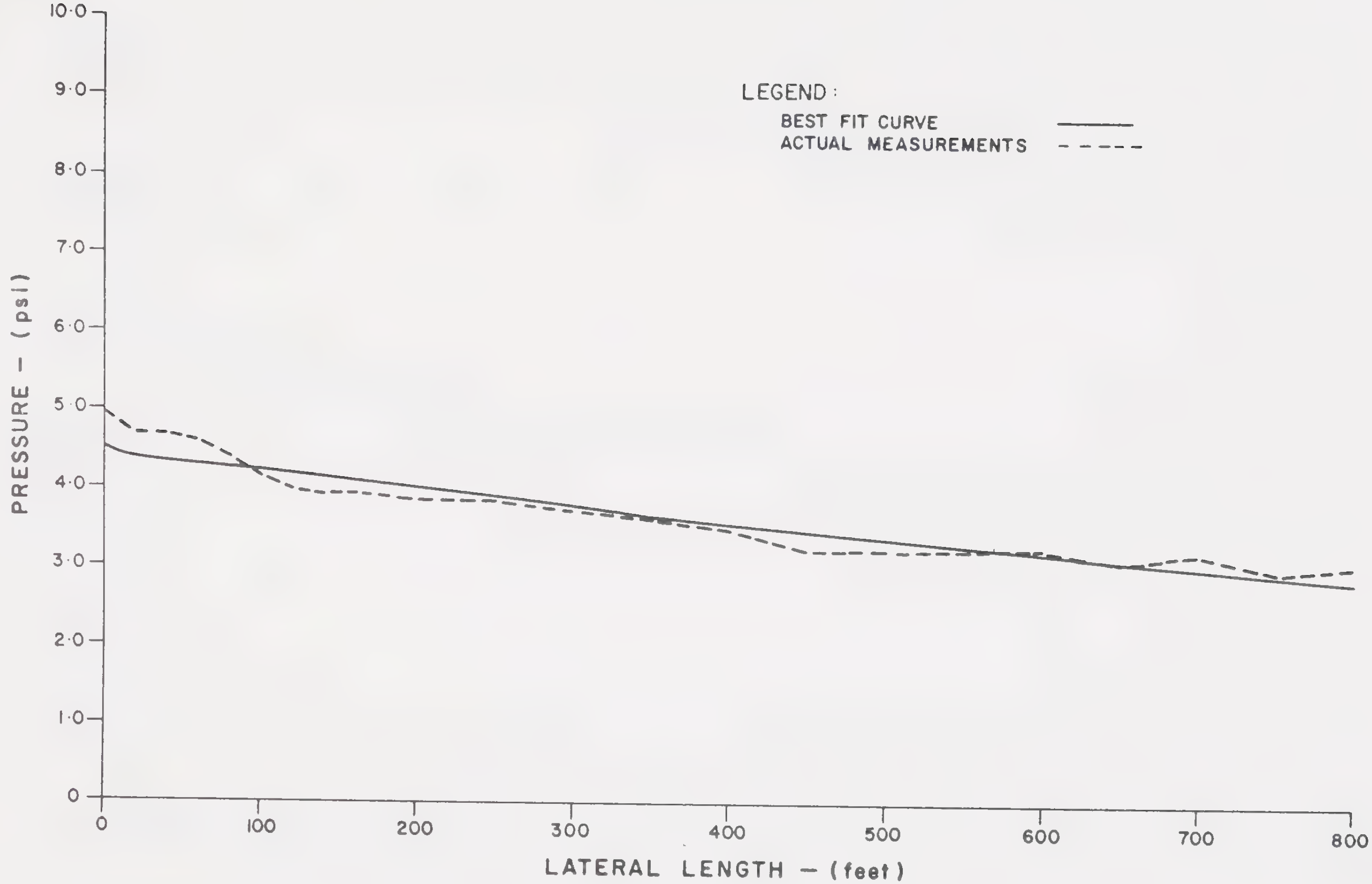


Figure 24. Pressure vs. Location Curve for Rinko at 10 PSI.

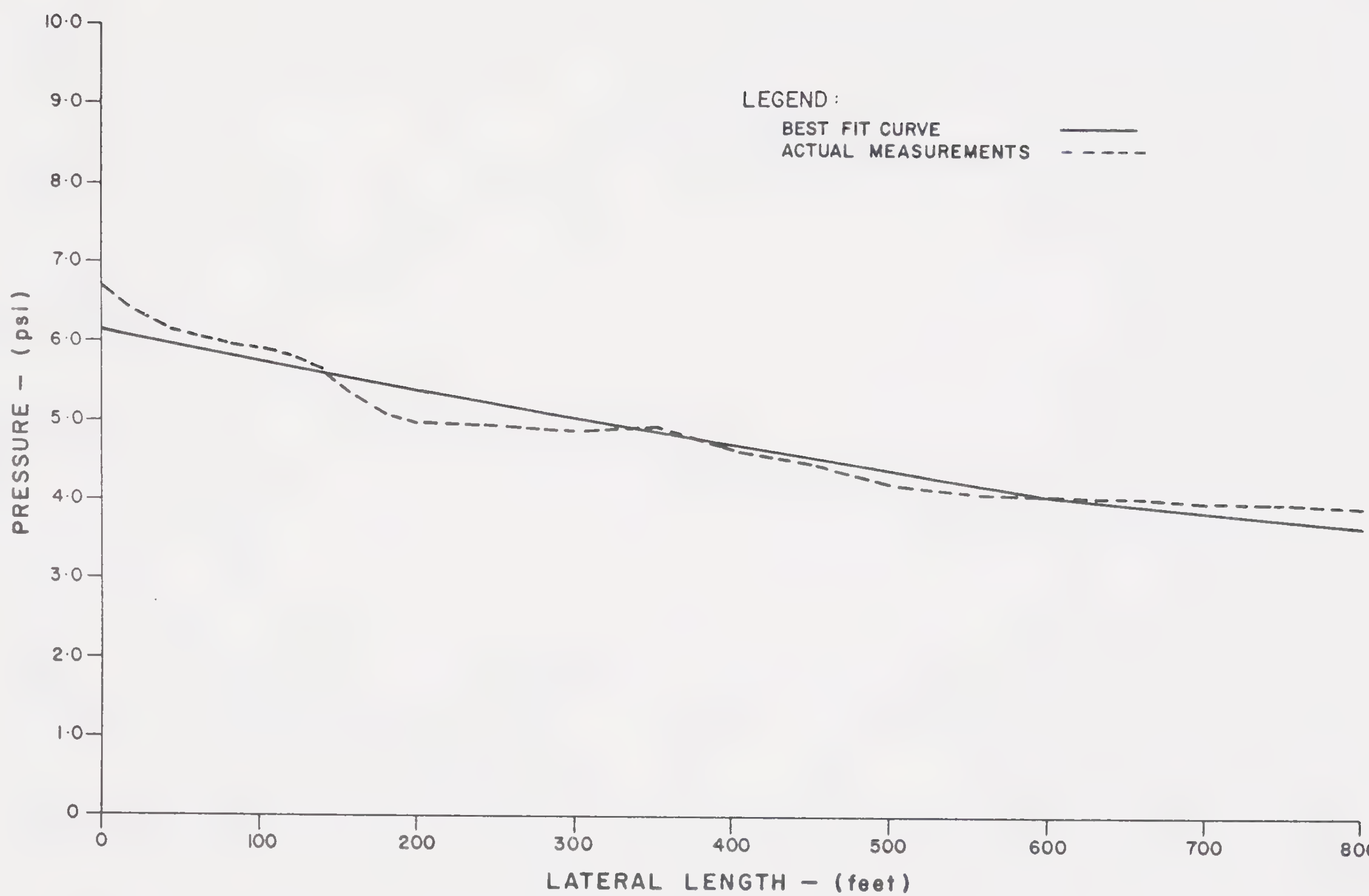


Figure 25. Pressure vs. Location Curve for Rinko at 15 PSI.

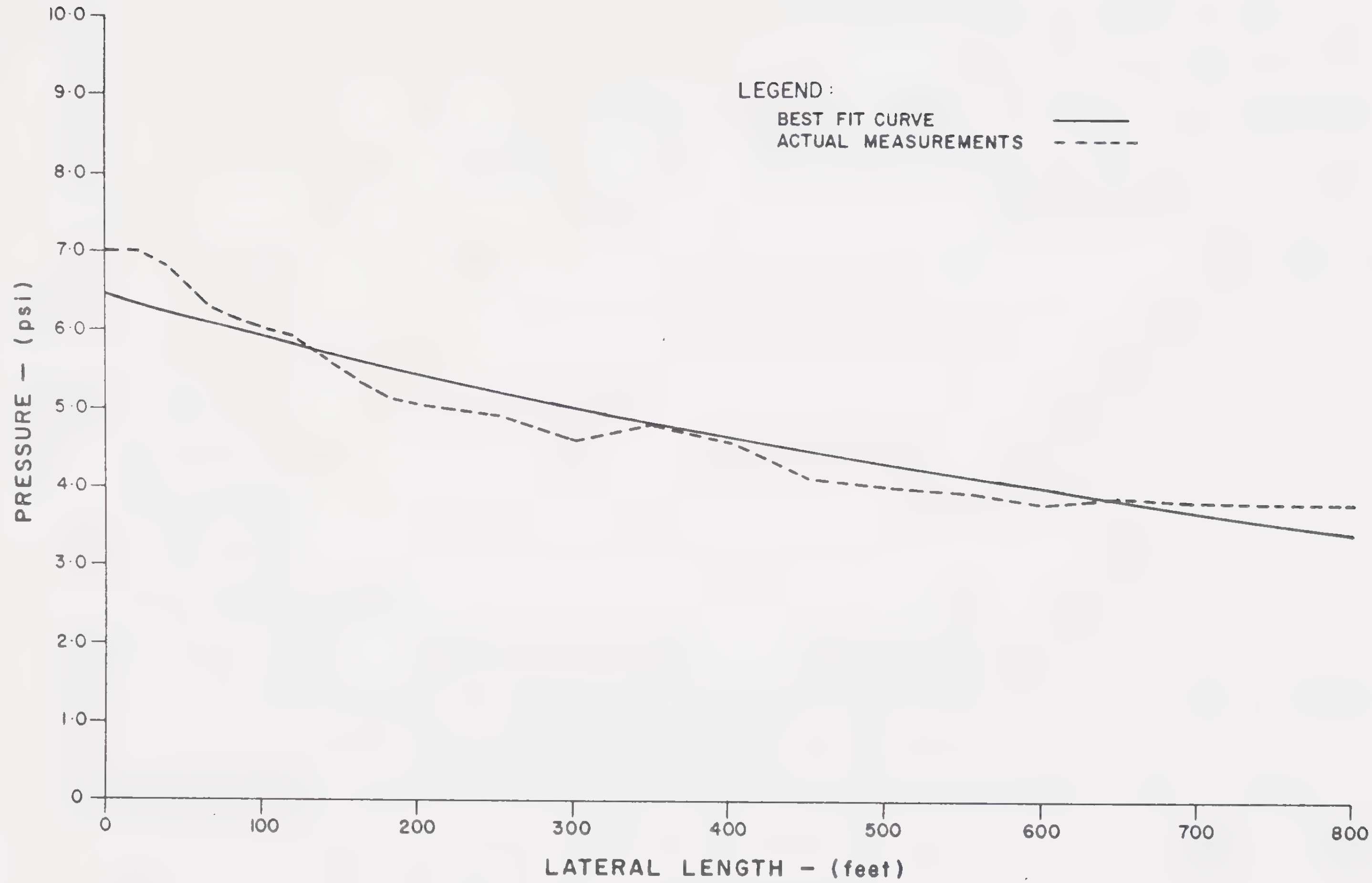


Figure 26. Pressure vs. Location Curve for Rinko at 2C PSI.

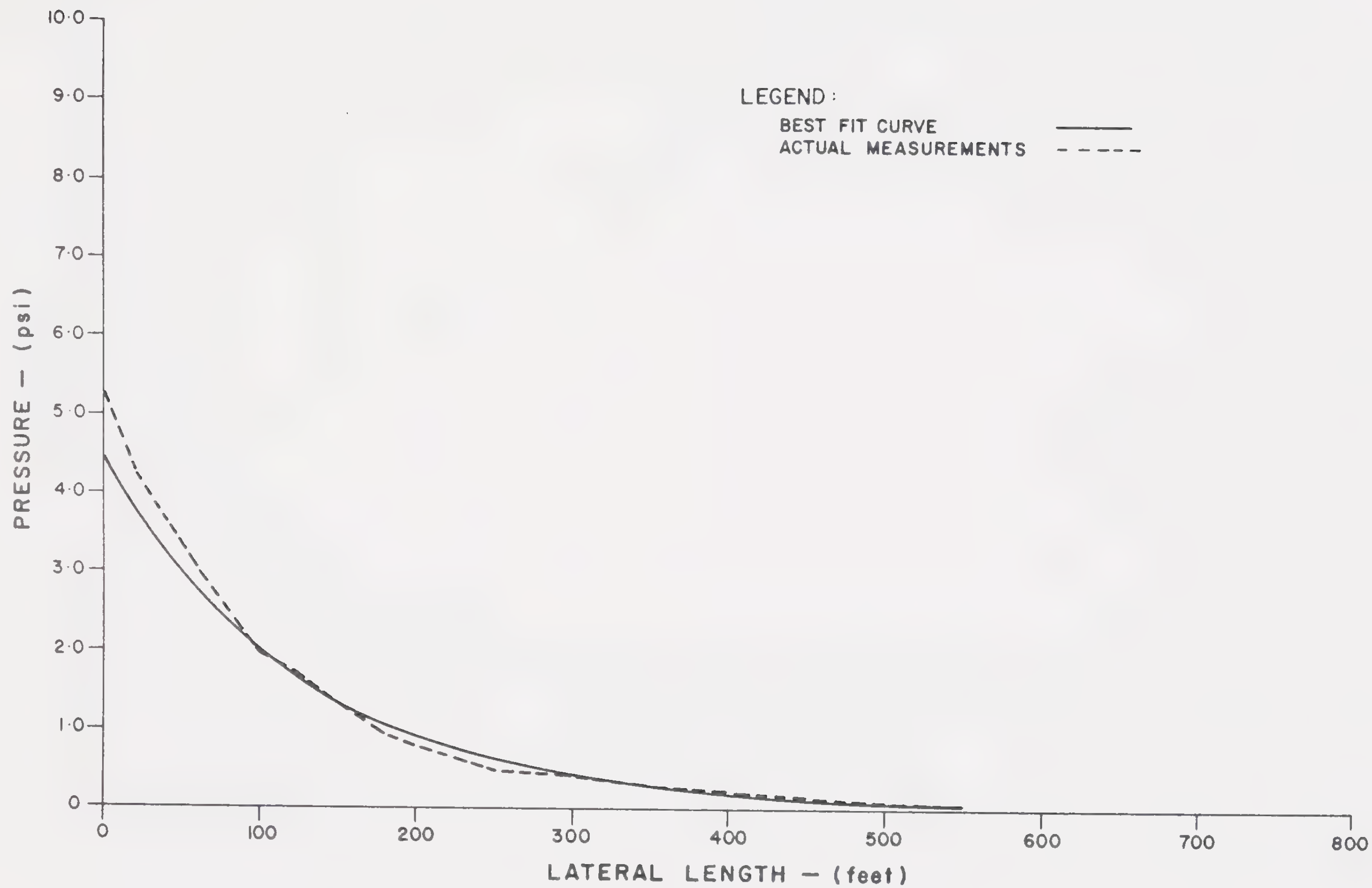


Figure 27. Pressure vs. Location Curve for Submatic at 5 PSI.

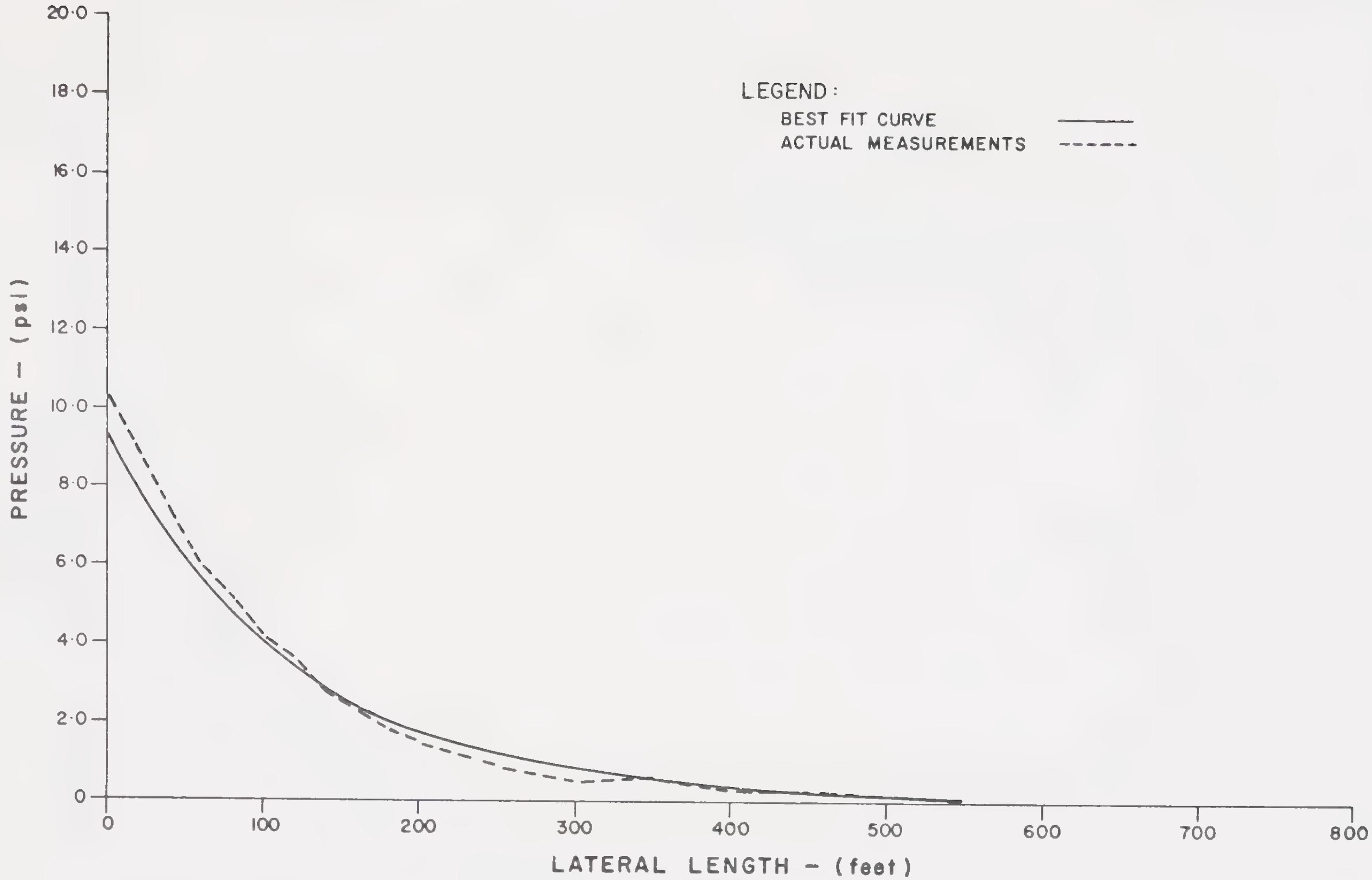


Figure 28. Pressure vs. Location Curve for Submatic at 10 PSI.

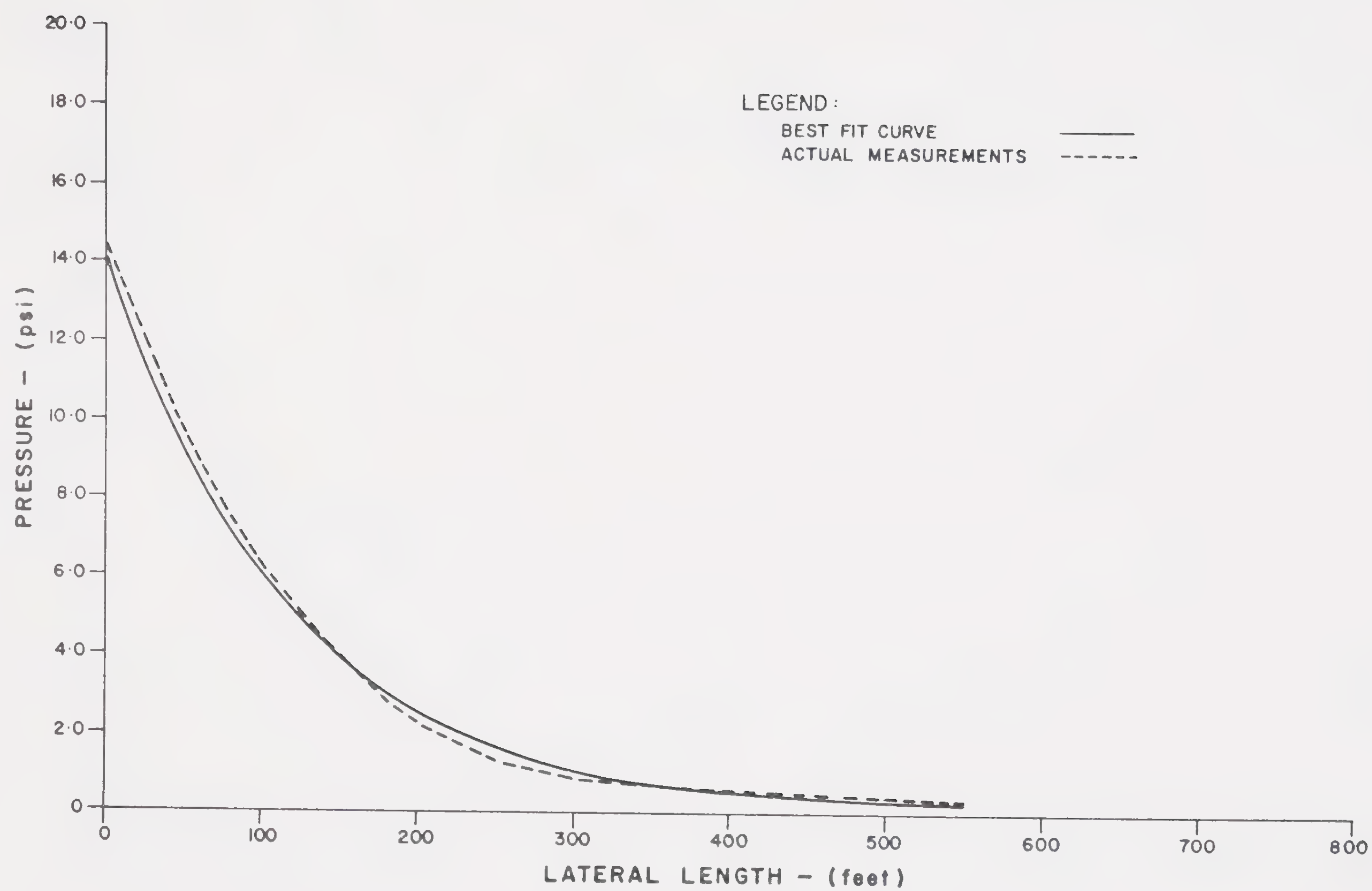


Figure 29. Pressure vs. Location Curve for Submatic at 15 PSI.

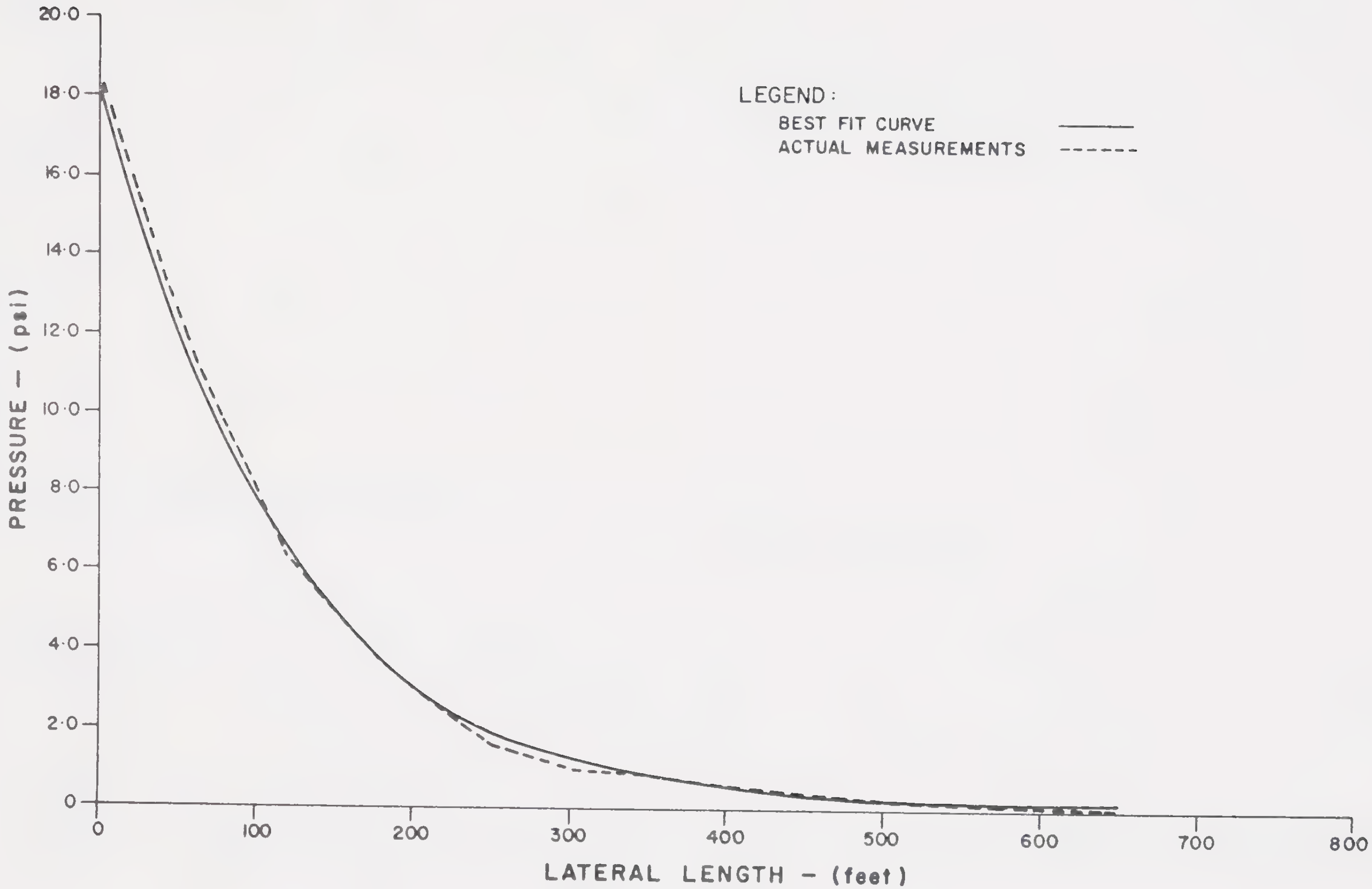


Figure 30. Pressure vs. Location Curve for Submatic at 2C PSI.

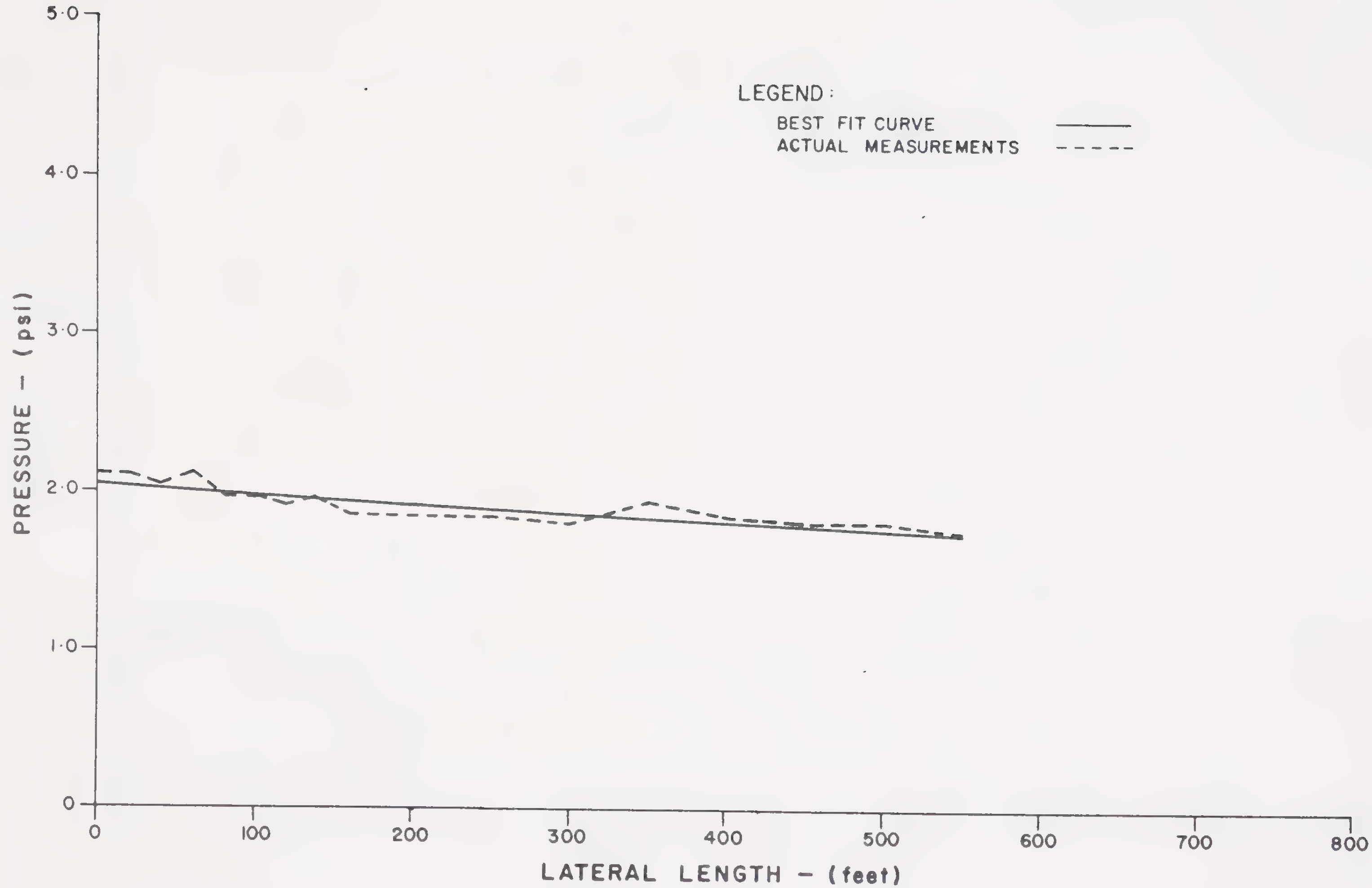


Figure 31. Pressure vs. Location Curve for Viaflo at 5 PSI.

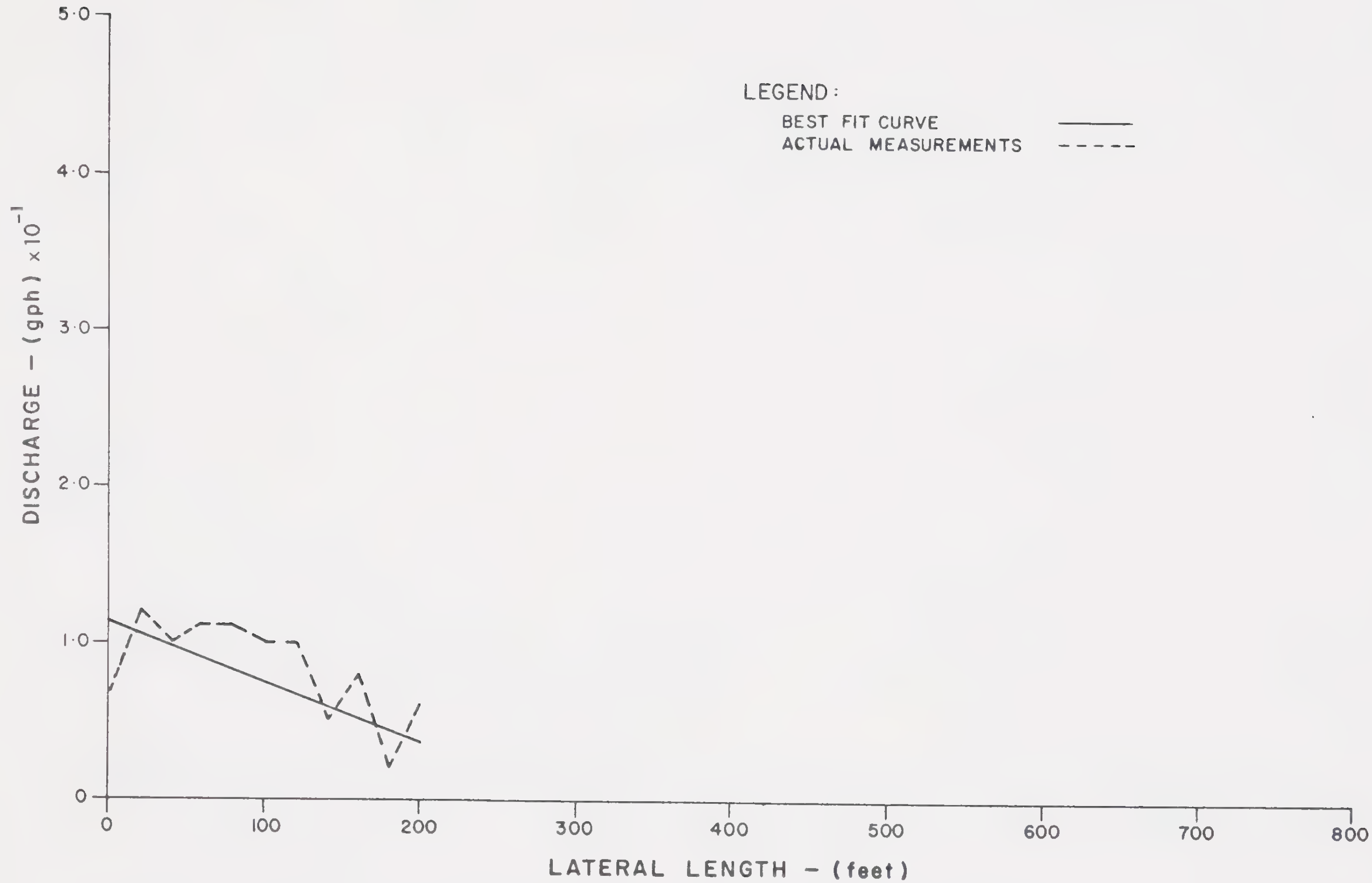


Figure 32. Discharge vs. Location Curve for Chapin Double Wall at 5 PSI.

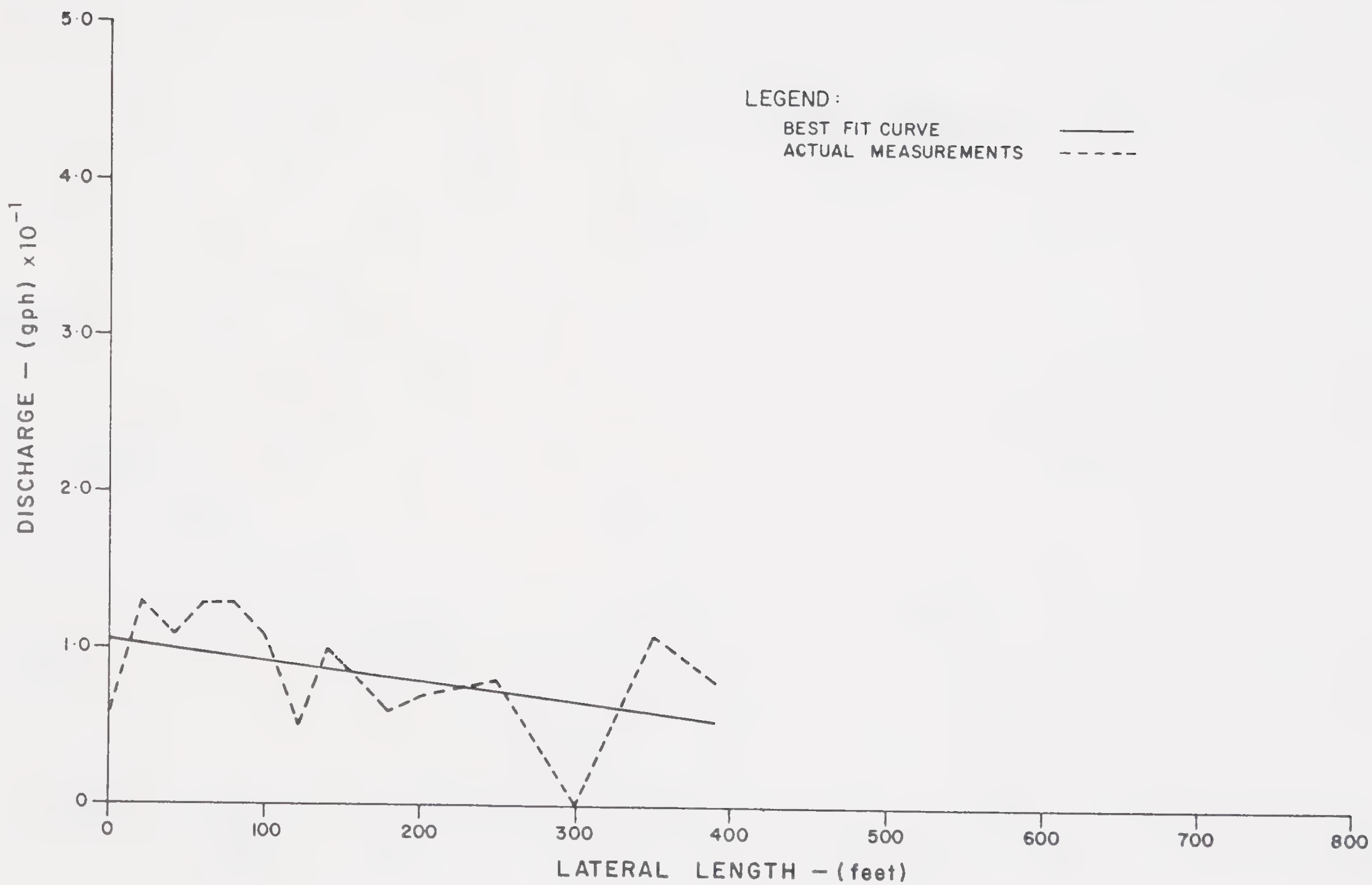


Figure 33. Discharge vs. Location Curve for Chapin Double Wall at 10 PSI.

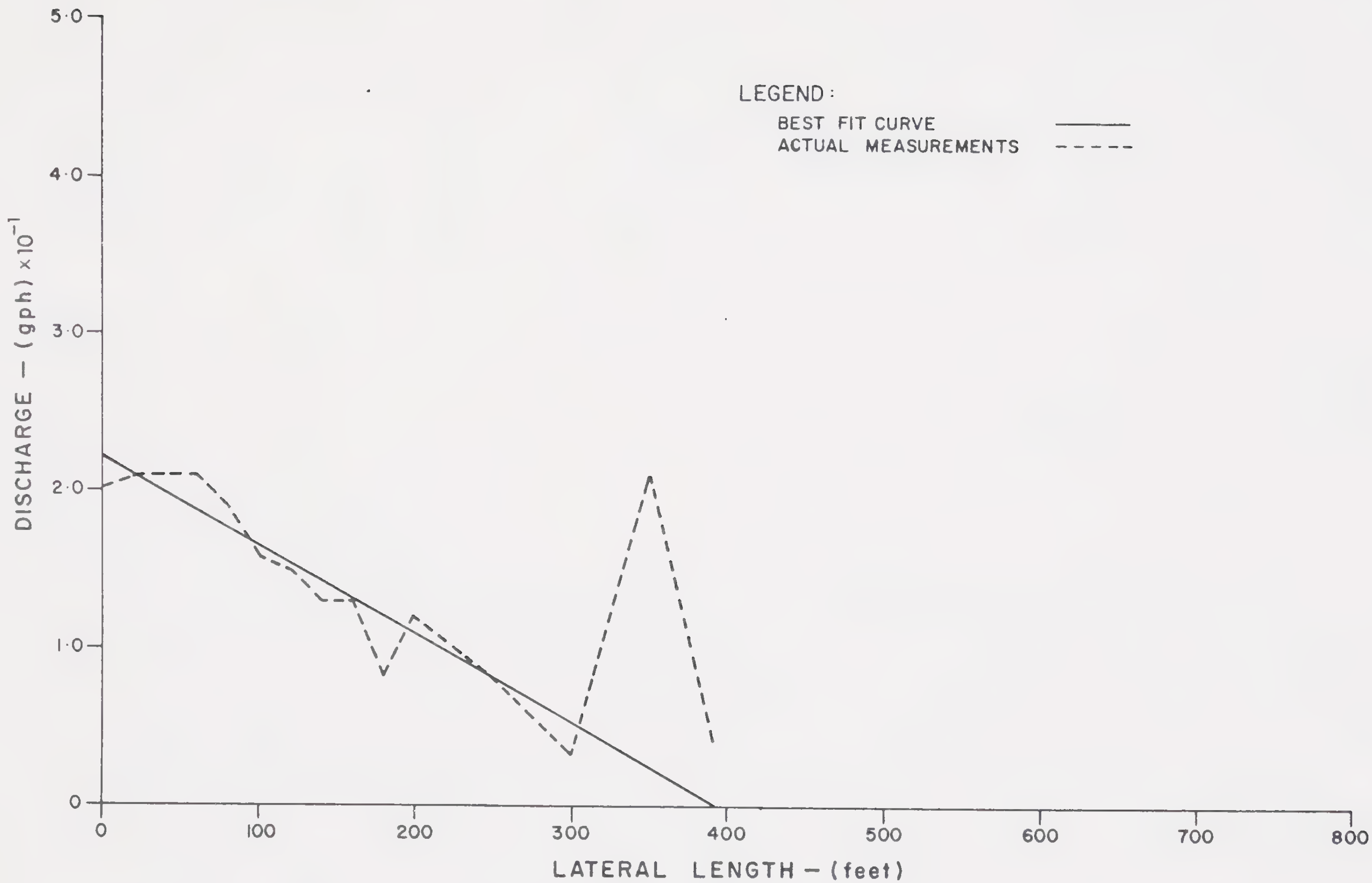


Figure 34. Discharge vs. Location Curve for Chapin Double Wall at 20 PSI.

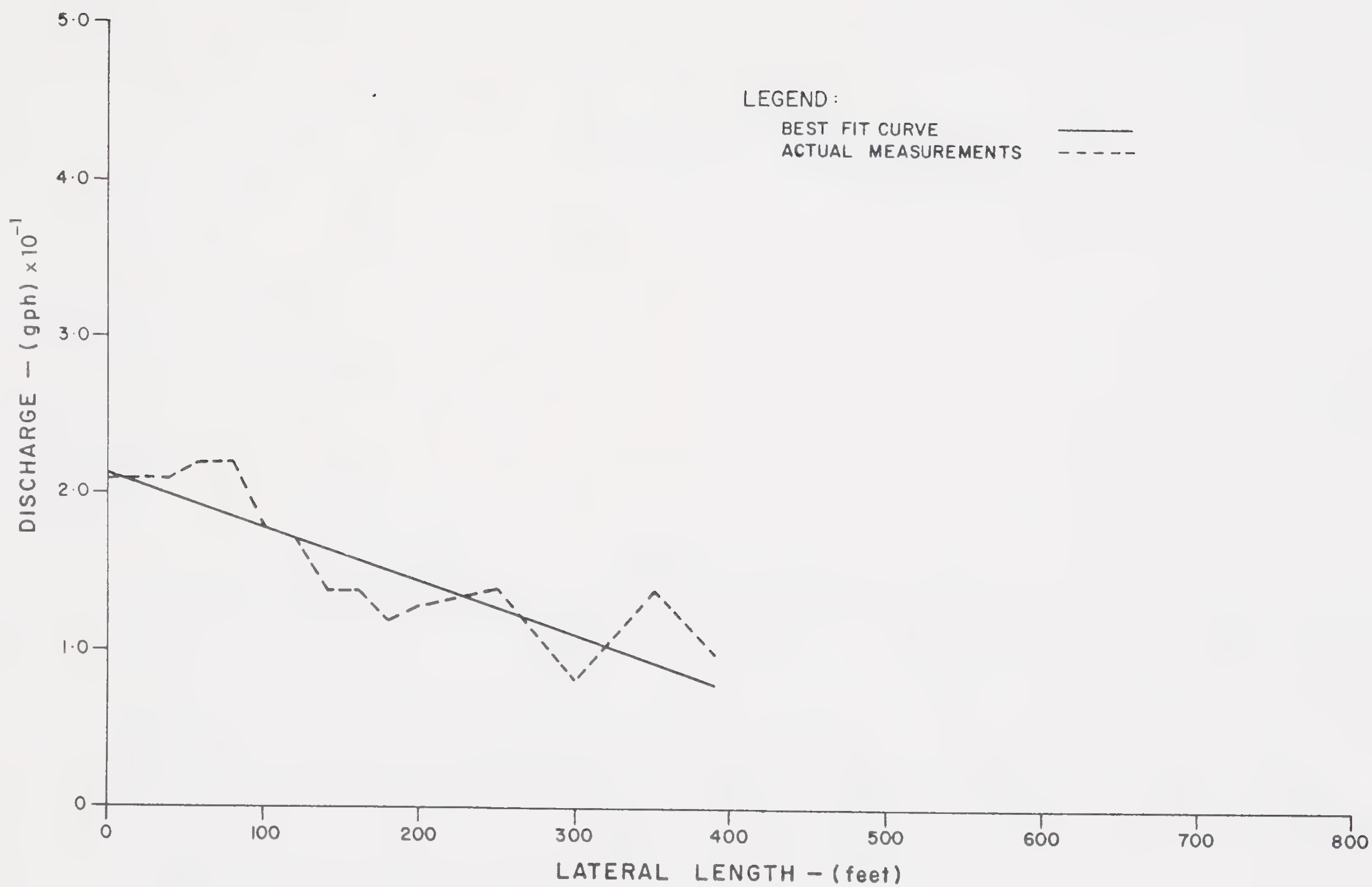


Figure 35. Discharge vs. Location Curve for Chapin Double Wall at 30 PSI.

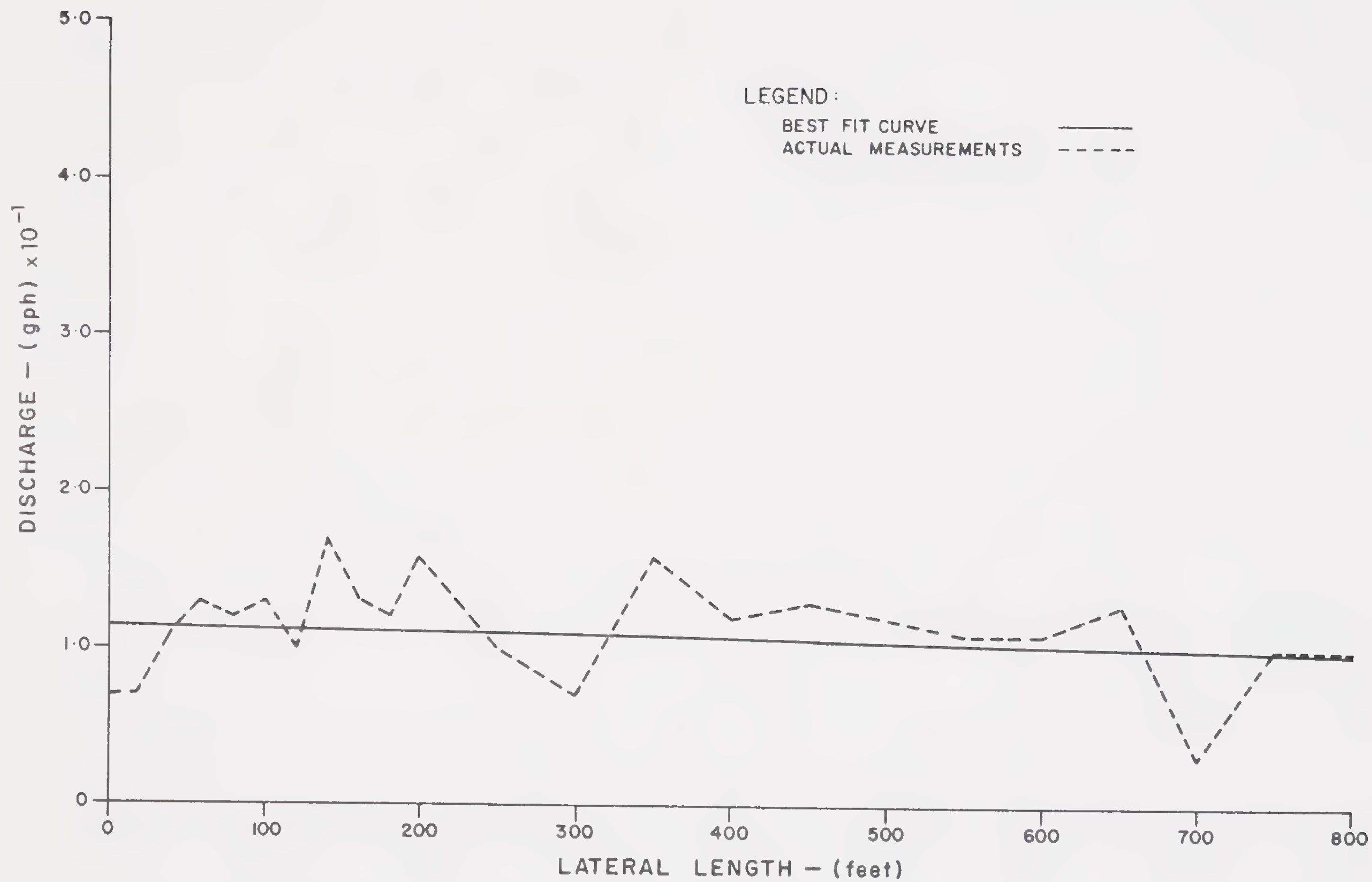


Figure 36. Discharge vs. Location Curve for Anjac Bi Wall at 5 PSI.

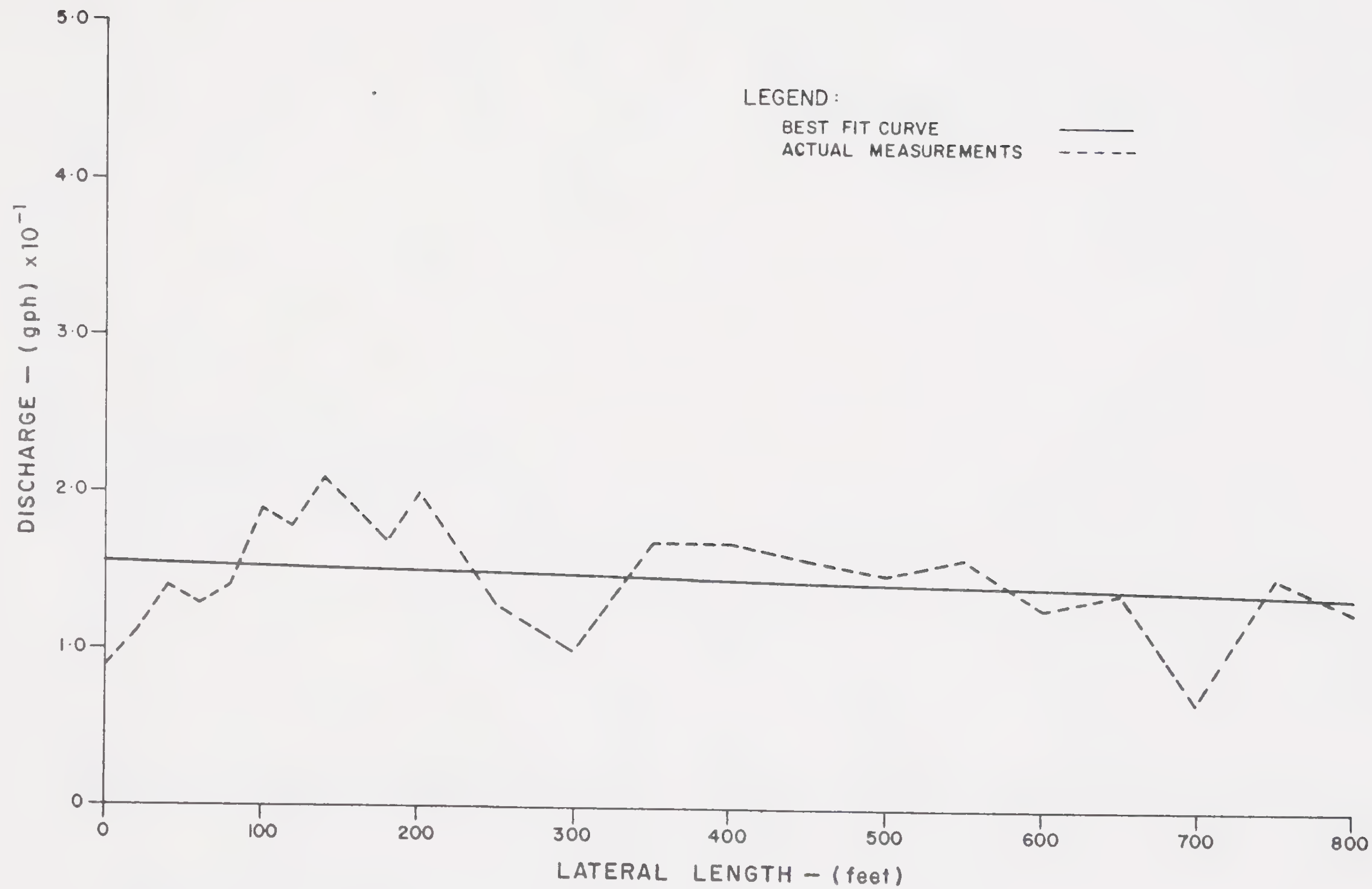


Figure 37. Discharge vs. Location Curve for Anjac Bi-Wall at 10 PSI.

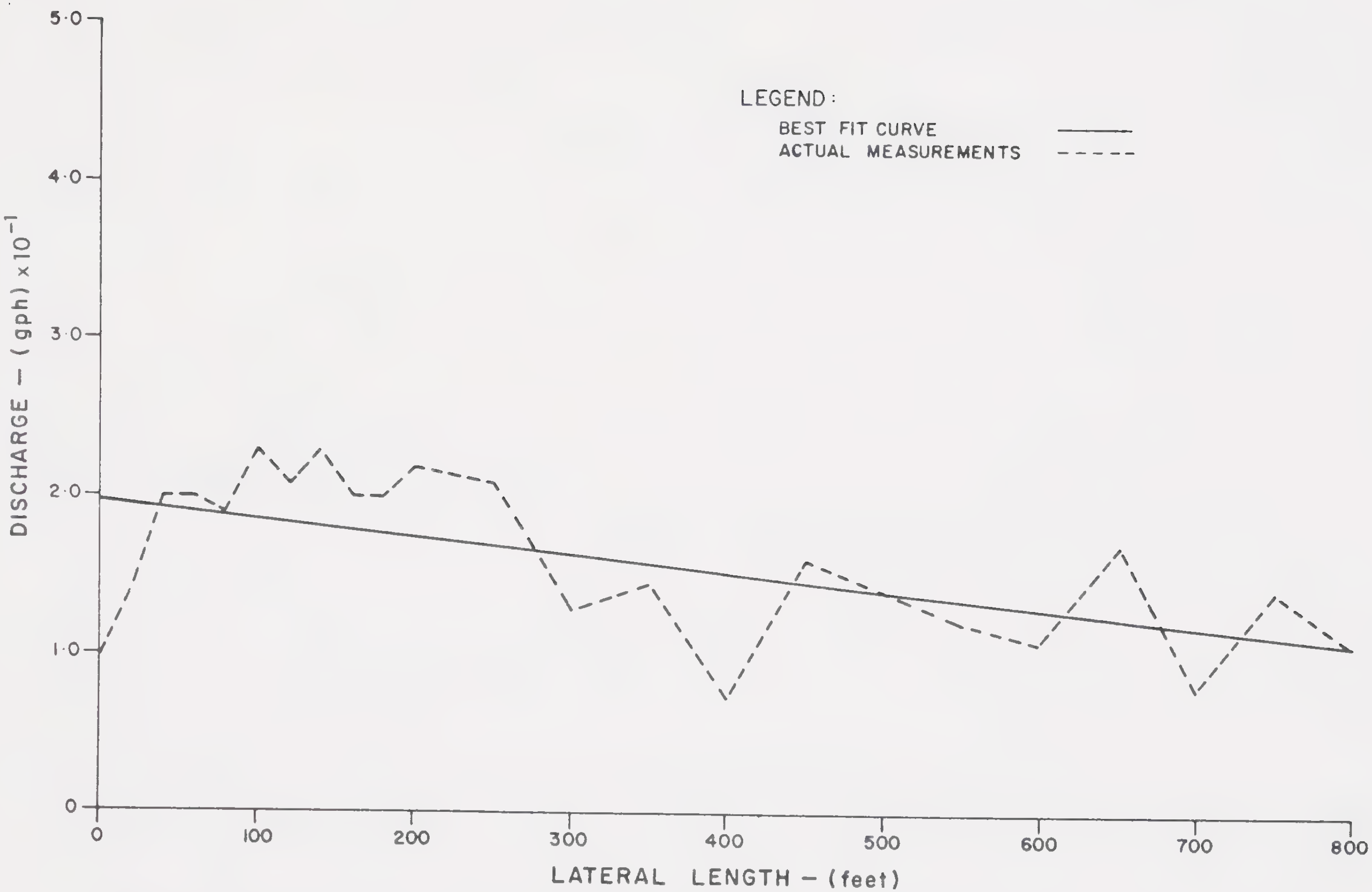


Figure 38. Discharge vs. Location Curve for Anjac Bi-Wall at 15 PSI.

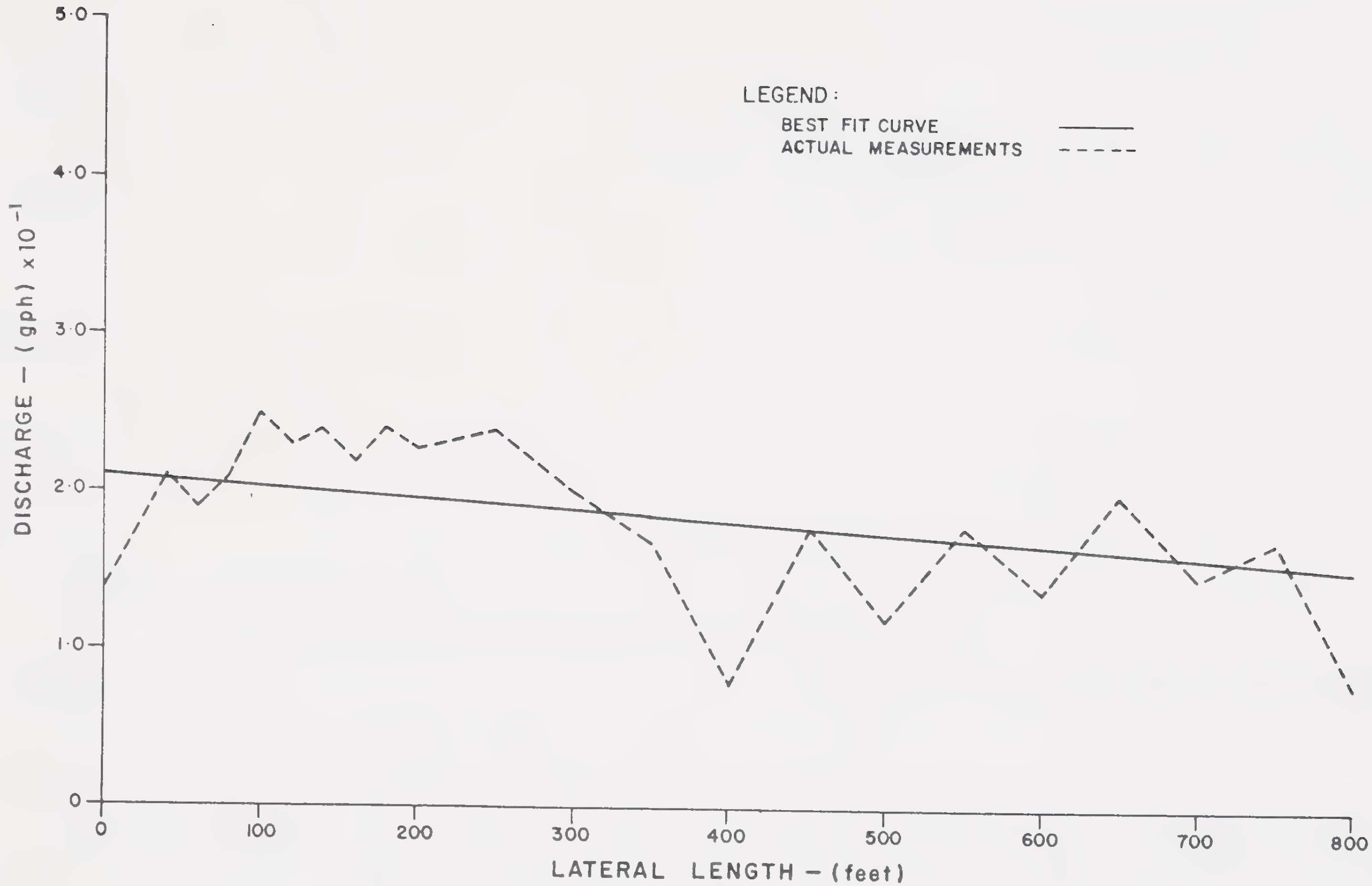


Figure 39. Discharge vs. Location Curve for Anjac Bi-Wall at 20 PSI.

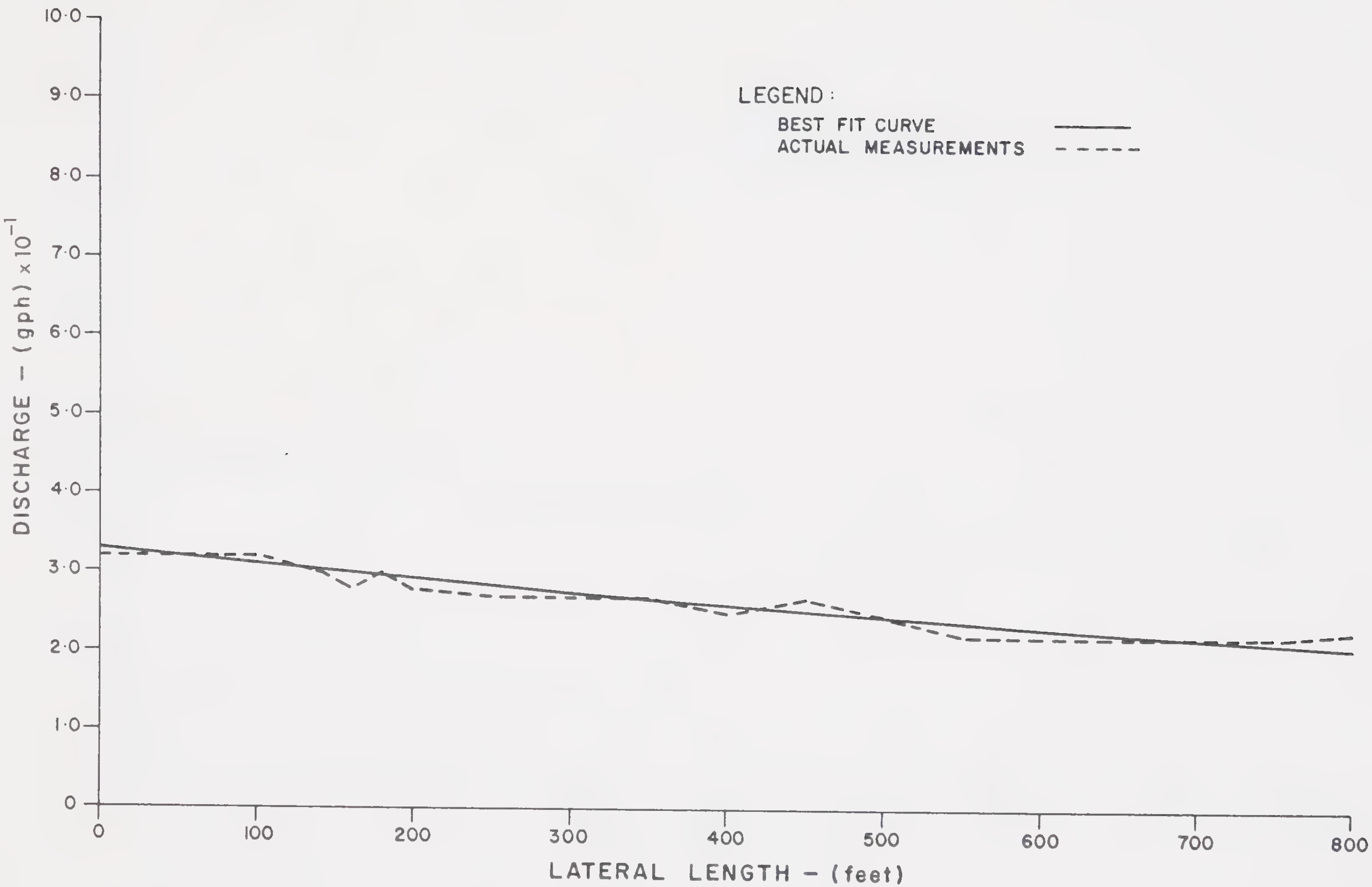


Figure 40. Discharge vs. Location Curve for Rinko at 5 PSI.

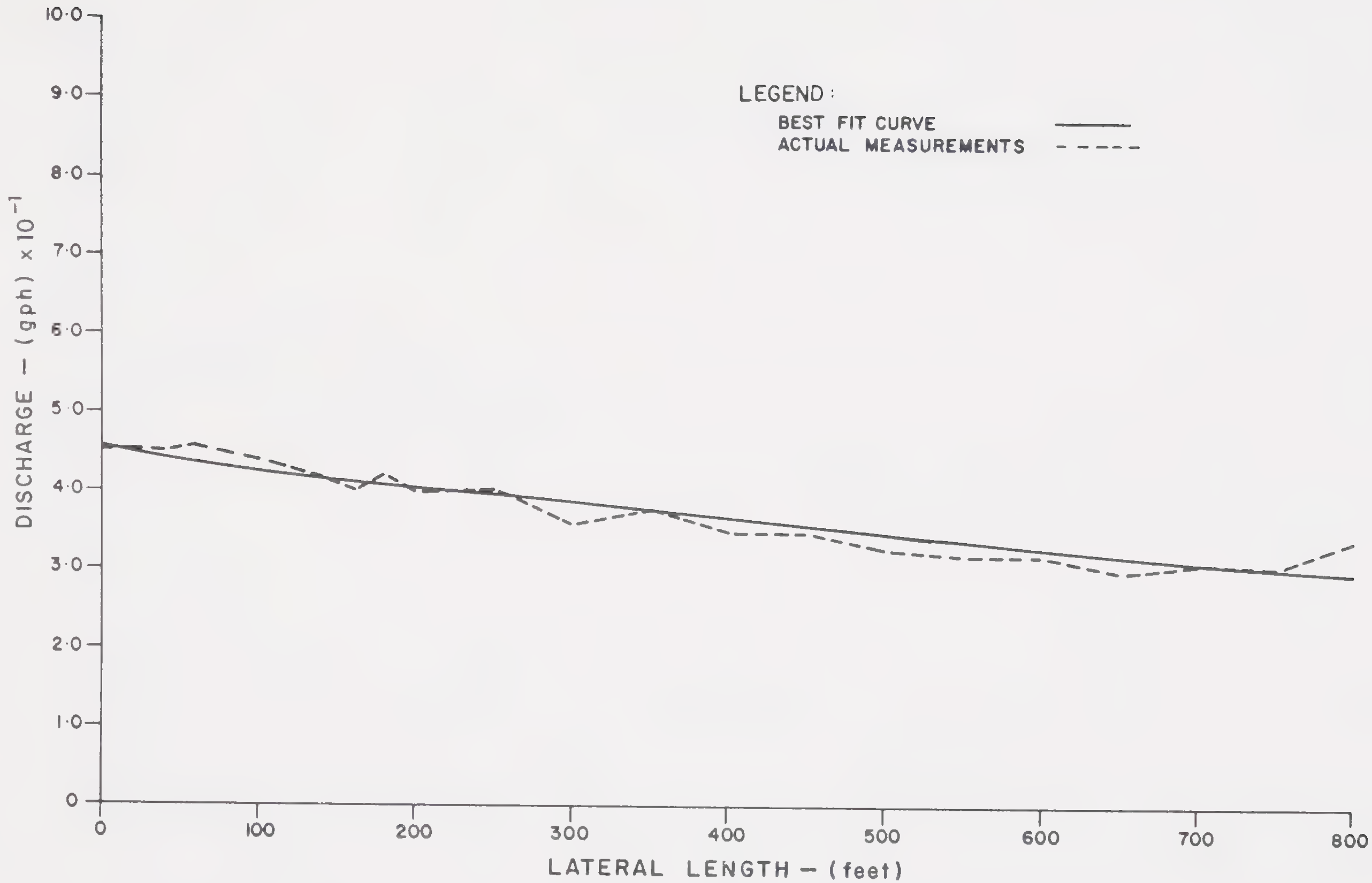


Figure 41. Discharge vs. Location Curve for Rinko at 10 PSI.

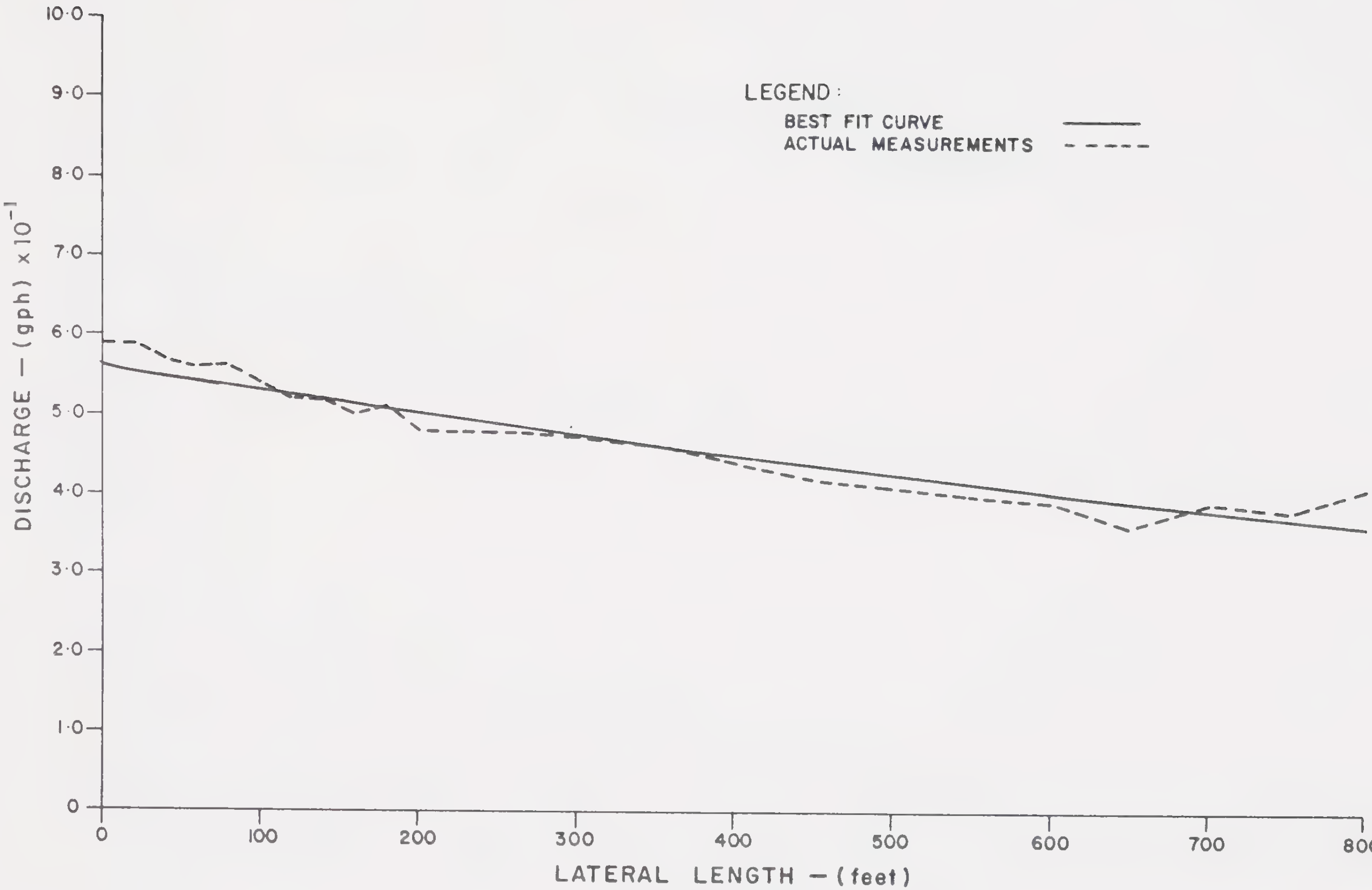


Figure 42. Discharge vs. Location Curve for Rinko at 15 PSI.

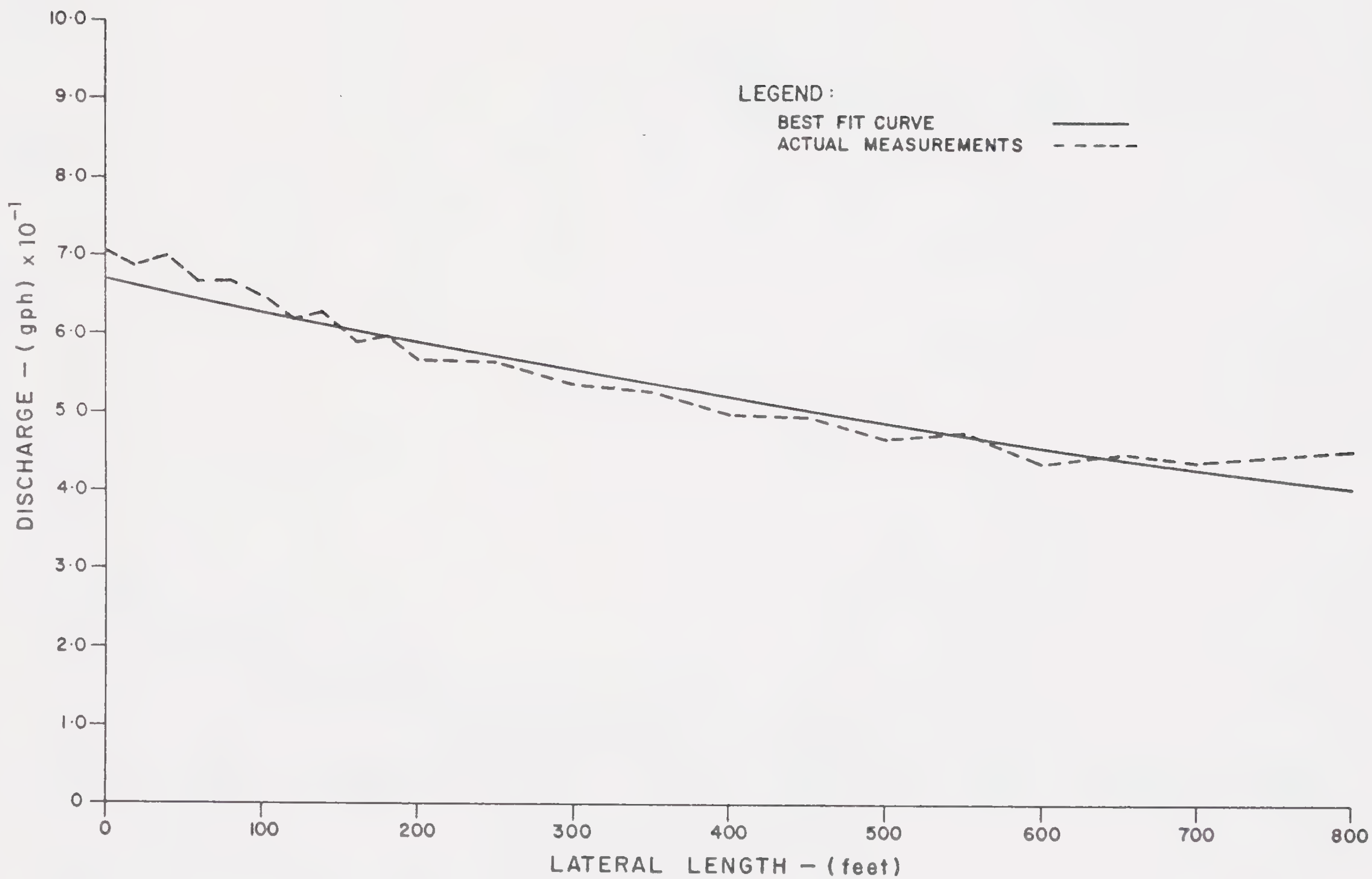


Figure 43. Discharge vs. Location Curve for Rinko at 20 PSI.

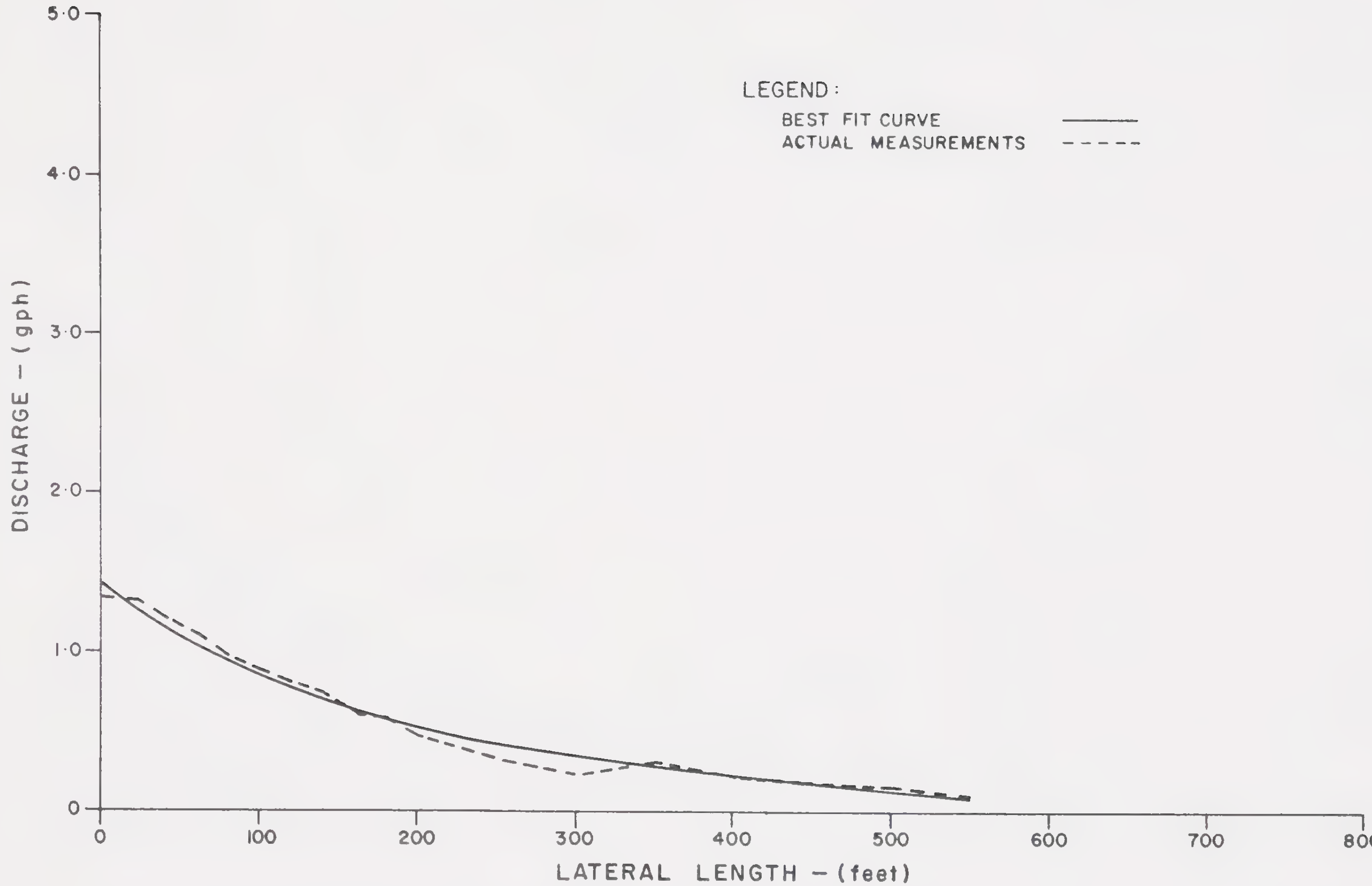


Figure 44. Discharge vs. Location Curve for Submatic at 5 PSI.

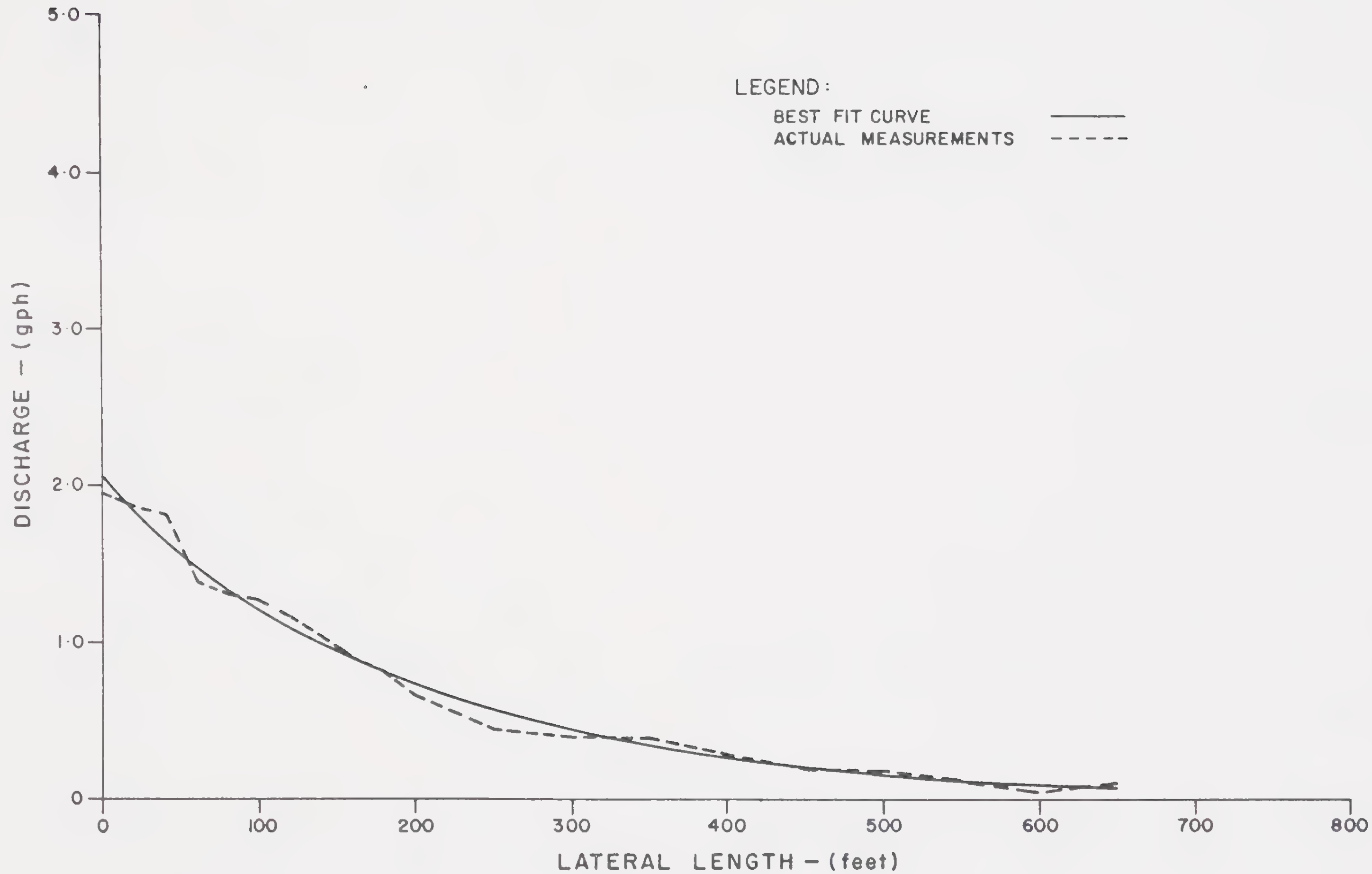


Figure 45. Discharge vs. Location Curve for Submatic at 10 PSI.

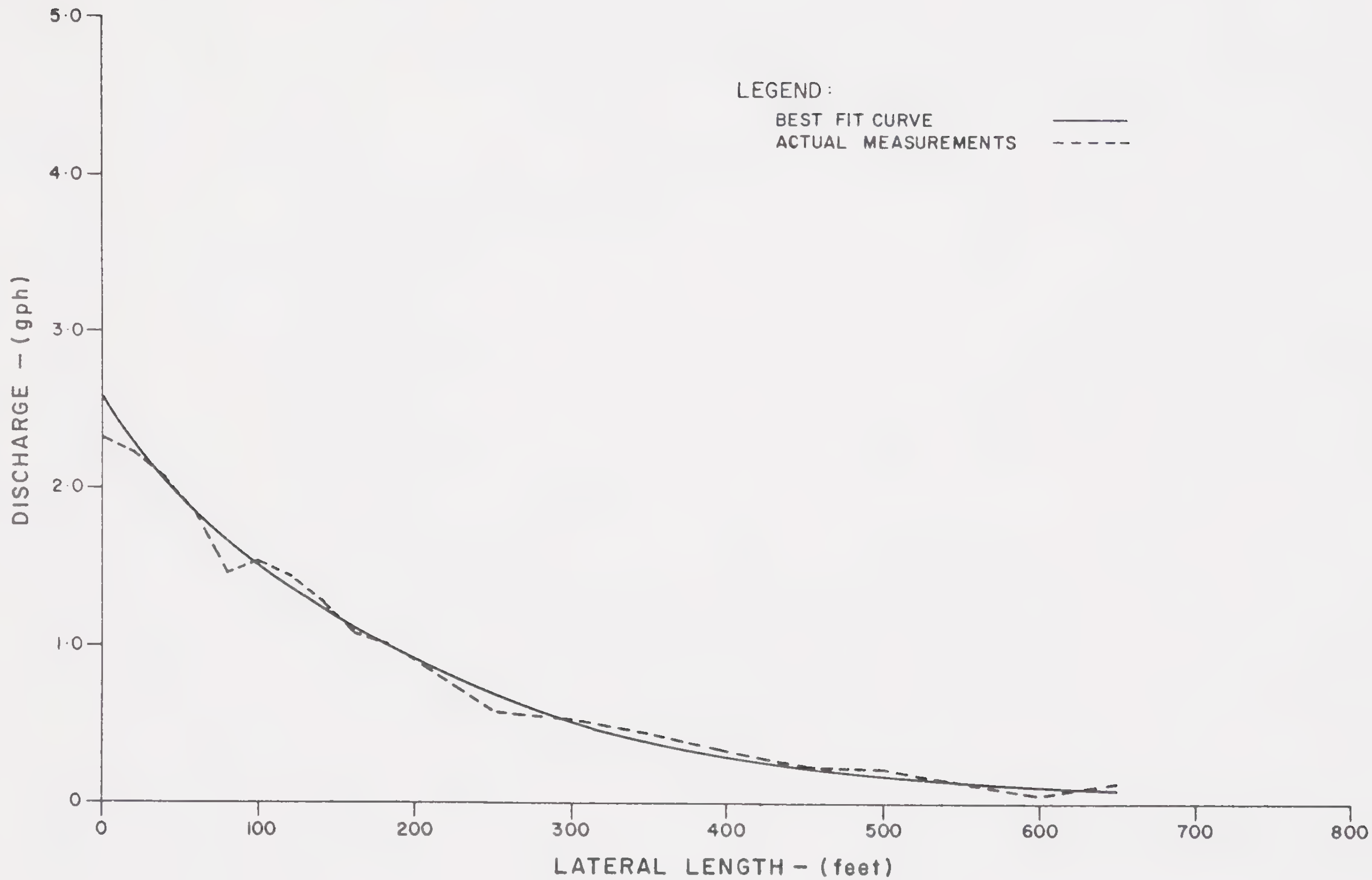


Figure 46. Discharge vs. Location Curve for Submatic at 15 PSI.

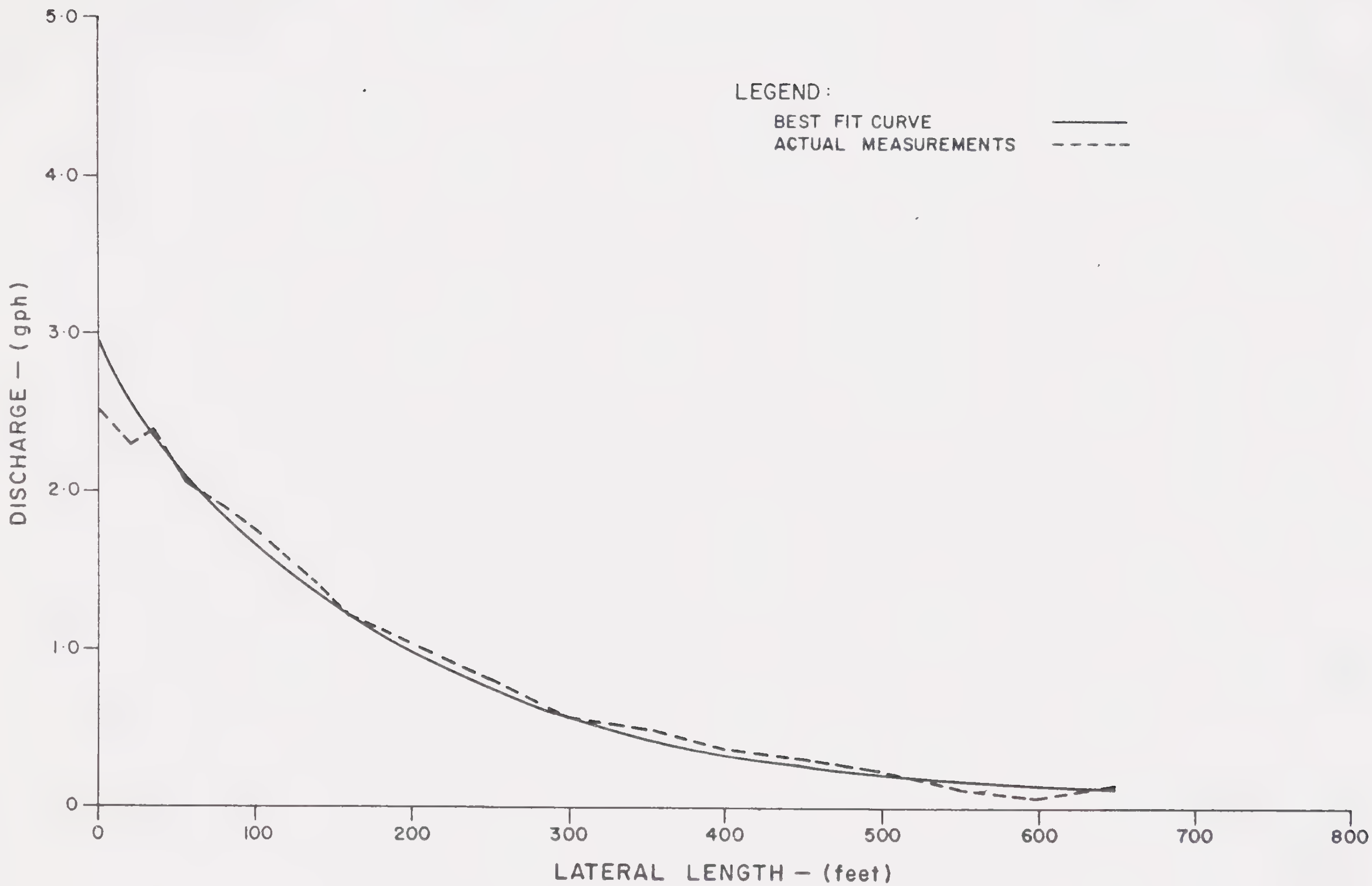


Figure 47. Discharge vs. Location Curve for Submatic at 20 PSI.

RESULTS AND DISCUSSION

The hydraulic performance of eight different systems was evaluated on the basis of results obtained from the 1973 field trials. The field tests were used to determine the characteristics of the trickle systems and also to verify and compare the published data of many researchers and manufacturers. Hydraulic design criteria can be determined on the basis of the measured parameters.

Hydraulic Performance of Different Systems.

The Chapin Double Wall system performed quite well. No difficulties were apparent except the occassional stoppage (5-8% of the orifices plugged). The 8 in. orifice spacing resulted in good wetted patterns. The coefficient of uniformity was, on the average, 70.4% (Table 1), which indicates a fairly uniform discharge. The pressure losses, however, were high and therefore the laterals can only be 400 ft long with a 30 psi operating pressure at the main line (Fig 18). The above mentioned length can be increased if the lateral is downslope, as is described in the section on design of trickle systems.

The Anjac Bi-Wall system operated without any major problems with a maximum of 10 - 13% of the orifices being plugged. The average coefficient of uniformity was relatively high at 80% (Table 1). A lateral length of 800 ft was used for all pressures under which the system was tested (Fig 19 - 22).

TABLE 1: LATERAL DISCHARGE UNIFORMITY.

Type	Mainline Pressure (psi)	Test Lateral Length (ft)	Coefficient of Uniformity, Cu* (%)	Average Orifice Discharge (US GPH) for length shown
Chapin Double-Wall	5	200	72.4	.08
	10	390	77.4	.08
	20	390	57.5	.12
	30	390	74.5	.14
Average			70.45	
Anjac Bi-Wall	5	800	81.0	.12
	10	800	84.7	.14
	15	800	74.3	.15
	20	800	80.2	.18
Average			80.0	
Rinko	5.7	800	89.7	.26
	10	800	88.2	.36
	15	800	88.0	.44
	20	800	87.4	.52
Average			88.3	
Submatic	5.5	550	27.8	.48
	10	650	23.4	.58
	15	650	25.6	.71
	20	650	24.4	.80
Average			25.3	

* $Cu = 100 \left(1 - \frac{d}{mn}\right)$

where: Cu is the coefficient of uniformity,

d is the summation of the deviations of the individual discharges from the mean discharge (weighted)

m is the mean (weighted)

n is the number of measuring points.

Pressure losses were low in all cases. An operating pressure ranging from 5 - 15 psi in the main line seems to be the optimum pressure for this system.

The Rinko system operated satisfactorily. No emitters plugged and no trouble occurred during the entire season. The average coefficient of uniformity of 88.3% was the highest for the systems tested. The maximum length of lateral tested was 800 ft and the optimum operating pressure was found to be 5 - 15 psi (Fig 23 - 26). The uniformity coefficient of the system decreased slightly with an increase in pressure (Table 1).

The Submatic system had a poor average coefficient of uniformity of only 25.3%. This indicates very poor discharge distribution along the lateral. The pressure losses are very high (Fig 27 - 30) and therefore only 550 - 650 ft lengths of lateral could be tested. On the other hand, no mechanical problems were observed.

The Viaflo system was considered a fairly good system. Tests were made at three different pressures in the main line - 5, 10 and 15 psi. Fig 31 shows the pressure losses for the first test pressure of 5 psi. A pressure higher than 5 psi caused breaks in the lateral. A point discharge could not be measured, only the total flow. A discharge of 0.03 gph per foot of length of lateral was computed for a 5 psi mainline pressure. The discharge uniformity was evaluated by viewing the wetted pattern from the top to the bottom end of the lateral. Very good uniformity was obtained for a lateral length up to 460 ft.

The Salco system required a lot of time to adjust all the emitters. Every time the water was turned on, readjustment of several

emitters was required and as soon as one emitter was adjusted, then the discharge would change and re-adjusting of the entire lateral was necessary. Because a similar problem occurred during the 1972 season, this system is considered operationally unsuitable.

The Miniflow Adjustable system was a trouble-free system with a coefficient of uniformity of 35.3%. This system is not suitable because even the minimum discharge was too high for growing vegetables.

The Uniflow system is a self-cleaning system with a complicated construction. Much labor was required to assemble the system. Under field conditions the system functioned very unsatisfactorily. Discharge fluctuations were extremely high and many breakages occurred. Because of the high cost and the above mentioned disadvantages the system is not considered suitable.

Evaluation of the Hydraulics.

Many papers, with theoretical and practical solutions, have been written on the hydraulic problems connected with the flow through a manifold, which is similar to a trickle irrigation lateral. Of the many different types of trickle irrigation systems, the Microtube system has been the most popular, especially in Australia. Various solutions of this system are reported in the literature and various formulas, nomographs, graphs and tables for the Microtube laterals have been computed. The length of lateral, the diameter and the length and spacing of microtubes are the most important variables in the solution. A universal theoretical solution which would fit all types of systems does not exist. There is a theoretical design solution developed in

Australia, called "Polyplot" (14). The pressure losses are regulated by using different pipe diameters along the laterals.

The various manufacturers of trickle systems do not give much precise information which would help in designing a system. The information that is given is often too theoretical. Field trials, with the particular types of systems, are often necessary in order to obtain hydraulic criteria which can be used for design purposes.

Comparison of results with the theoretical computations.

An attempt was made to compute pressure losses, discharge and length of lateral by using an IBM 360 computer. Application of the Zetche-Newman solution was tried (see Review of Literature), however, this method was not satisfactory. The solution whereby the pressure at the end of lateral must be chosen is not satisfactory. For example, if a pressure of 4.3 psi was chosen for the Chapin Double Wall system at the end of the lateral, a length of 200 ft was computed. If the end pressure in the same lateral was lowered to 0.25 psi, a length of 220 ft was computed. From these solutions, it was obvious that the optimum length of lateral should be between 200 and 220 ft despite a significant variation in the pressure head. The test measurements showed that for a head of 5 psi in the main line, the lateral length should be 200 ft and for a head of 30 psi in the main line, the length of the lateral should be 390 ft (Table 1a - 4 a in the Appendix).

Large pressure losses between the main line and the lateral are due to the design of the system. The main line (1.5 - 2 in. diameter) is joined to the lateral with a connecting tubing of about 1/8 in. diameter. A similar problem appeared with use of another

"double wall" system, the Anjac Bi Wall.

The combination of I-pai-Wu - Gitlin's solution and Zetche-Newman's solution was also tried on the IBM 360 computer. With the I-pai-Wu - Gitlin's solution, the Blasius formula for the friction coefficient was substituted by computing the friction coefficient using the Reynolds number and Zetche - Newman's curves for smooth pipes. The orifice discharge was computed according to the formula:

$$Q = AC\sqrt{2gH} \tag{8}$$

where Q is the discharge in $ft^3/sec.$

A is the area of the orifice in ft^2,

C is the coefficient of discharge,

g is the acceleration due to gravity ft/sec^2

and H is the pressure head ahead of the orifice in ft.

By subtracting the orifice discharge from the total flow, the new flow was obtained and this was then used for computation of the velocity and thus the Reynolds number. Also, the velocity was decreasing. The average discharge using I-pai-Wu-Gitlin's method therefore was not used. The coefficient C was computed from the formula (8) at the beginning of the lateral, when all other variables in the equation were known. The results obtained were not satisfactory (Table 2).

The length of the lateral is the most important variable in this case and therefore was used for the comparison.

TABLE 2. MEASURED AND COMPUTED LENGTHS OF LATERAL.

System	Main line pressure, psi	Computed length, ft	Measured length, ft
Anjac Bi Wall	5.5	136	800
Anjac Bi Wall	10	548	800
Submatic	5	340	260
Submatic	10	340	300

Pressure losses.

The theoretical computation and design proved to be inaccurate and therefore more experimental data will be needed. However, the field data obtained from the Brooks trial can be used for design of future trickle irrigation systems in Alberta. The results of measurements are summarized in tables (Table 1a - 17a in the Appendix). The data were plotted and the best fit curves were computed using the Wang computer. Pressure reading data in the tables are in psi and all readings which were measured in ft were converted to psi. Several types of curves were computed and the one with the best coefficient of determination, R^2, was chosen. (R^2 is the correlation coefficient squared). Table 3 gives the results for all systems selected. The pressures given for different systems are pressures which were in the main line at the head of the lateral during the test period.

Lower coefficients of determination for both the double hoses, Chapin and Anjac, are due partly to the low pressures which were measured at the first 0.2 ft of lateral. The explanation is that the

TABLE 3. BEST FIT CURVES FOR PRESSURE DISTRIBUTION.

System	PSI	Equation*	R^2
Chapin Double Wall	5	$Y = 0.296 \times 0.993^x$	0.52
	10	$Y = 0.499 \times 0.994^x$	0.88
	20	$Y = 1.063 \times 0.993^x$	0.78
	30	$Y = 1.597 \times 0.994^x$	0.87
Rinko	5	$Y = 5.458 \times 0.999^x$	0.91
	10	$Y = 4.498 \times 0.999^x$	0.90
	15	$Y = 6.176 \times 0.999^x$	0.93
	20	$Y = 6.397 \times 0.999^x$	0.90
Anjac Bi Wall	5	$Y = 1.014 \times 0.999^x$	0.71
	10	$Y = 3.700 \times 0.999^x$	0.86
	15	$Y = 4.267 \times 0.999^x$	0.83
	20	$Y = 5.293 \times 0.999^x$	0.82
Submatic	5	$Y = 4.370 \times 0.992^x$	0.97
	10	$Y = 9.316 \times 0.991^x$	0.99
	15	$Y = 14.091 \times 0.991^x$	0.99
	20	$Y = 18.368 \times 0.991^x$	0.99
Viaflo	5	$Y = 2.045 \times 0.999^x$	0.66

* Y is the pressure in psi
x is the lateral length in ft

water has a very high velocity in the connecting tube and therefore at the beginning of the lateral. With increasing distance, the velocity is decreased and pressure is higher.

Discharge.

The discharge readings are summarized in Tables 1a - 17a in the Appendix. The curve fitting was done as for the pressure losses and the curves with the best coefficients of determination were chosen. Table 4 gives the equations for the best fit curves. For the Chapin Double Wall and Anjac Bi-Wall system, the standard error of the estimate was computed. The need for computation of the standard error was the wide fluctuations in discharge along the lateral. There can be several explanations for these fluctuations.

1. The main cause may be that the flow changes from turbulent to laminar with increasing length. The Reynolds number varied within the limits for both laminar and turbulent flow (the transition zone according to the Moody diagram).
2. The orifices do not have a perfect circular shape. This was observed through a microscope. With changing pressure and temperature, some deformations of shape may occur although there is no definite proof. Similarly, no explanation was given in the paper by Vaziri and Bui (30). The authors measured pressure and discharge losses of the Anjac Bi-Wall system in 1972. The discharge also varied a significant amount and therefore average discharge for a particular length of lateral was used.

TABLE 4. BEST FIT CURVES FOR DISCHARGE.

System	PSI	Equation*	R^2	Standard Error
Chapin Double Wall	5	$Y = 0.113 - 0.0003X$	0.56	0.023
	10	$Y = 0.102 - 0.0001X$	0.16	0.033
	20	$Y = 0.222 - 0.0006X$	0.93	0.017
	30	$Y = 0.213 - 0.0003X$	0.77	0.022
Rinko	5	$Y = 0.327 \times 0.999^x$	0.84	
	10	$Y = 0.452 \times 0.999^x$	0.90	
	15	$Y = 0.562 \times 0.999^x$	0.91	
	20	$Y = 0.673 \times 0.999^x$	0.92	
Anjac Bi Wall	5	$Y = 0.119 - 0.00003X$	0.04	0.031
	10	$Y = 0.155 - 0.00002X$	0.02	0.034
	15	$Y = 0.196 - 0.0001X$	0.33	0.039
	20	$Y = 0.212 - 0.00007X$	0.20	0.037
Submatic	5	$Y = 1.391 \times 0.995^x$	0.98	
	10	$Y = 2.046 \times 0.994^x$	0.98	
	15	$Y = 2.537 \times 0.994^x$	0.99	
	20	$Y = 2.918 \times 0.994^x$	0.97	

* Y is the discharge in GPH.

x is the lateral length in ft.

An interesting part of the problem is that such a large variation occurs only with relatively soft double hoses. Some of the extreme points were tested for significance. It was found that all the points should be included in the curve except the discharge for the 20 psi pressure measured on the Chapin Double Wall system at 350 ft (Fig 34). This point was found not to be part of the sample population.

The very low coefficients of determination were computed for both "Double Walls". Extremely low coefficients were obtained for the 5 psi and 10 psi pressure. In all cases, it was difficult to fit a curve (Fig 32 - 39). The standard error of the estimate should give the designer an indication of the accuracy that can be expected in designing a particular system. For the Rinko and Submatic systems, the standard error was not computed because the curve fit was good.

The curves for the DuPont Viaflo system were not computed. For this system, the discharge per foot may be used for design purposes (Fig 31).

Design of trickle irrigation systems.

On the basis of the computed curves, the nomographs for a hydraulic solution for the four systems - Rinko, Anjac Bi-Wall, Chapin Double Wall and Submatic, were constructed (Fig 48 - 51).

The technique for using the nomographs is basically the same for all four systems. The following example explains their use:

Given: A trickle irrigation lateral 300 ft long with a 0.5% upslope and using the Rinko system with emitters 2 ft apart,

Find: The pressure at the end of the lateral, the discharge rate, and the operating pressure in the main line.

Solution: Using Fig 48 find the lowest pressure in the main line, which is 5 psi, therefore, use all lines with a number 1.

1. Connect the zero at "Distance of Lateral" Line Number 1 with 0_1 point. The line intersects the "Lateral Pressure" line at 5.5 psi, which is the pressure at the head of lateral. If the line is extended, it intersects the "Discharge US GPH" at 0.33 GPH, which is the discharge at the head of lateral.

2. Connect the 300 ft point at "Distance of Lateral" with the 0_1 point again. The line intersects the "Lateral Pressure" line at 4.8 psi which is the pressure at 300 ft of lateral length with no slope.

3. From the table of "Correction for Slope in PSI", find the value for 300 ft for a slope of 0.5%. Because the lateral is upslope, a value of 0.6 PSI must be subtracted from 4.8 psi. The result is 4.2 psi, which will be the pressure at the end of the 300 ft lateral.

4. Using the point 0_1 as a pivot and turning the ruler to a value 4.2 psi, the extended line intersects the "Discharge US GPH" line again at a point 0.225 or 0.23 GPH.

The difference in discharge is then: 0.33 - 0.23 - 0.10 GPH, which is within 30% of the discharge at the lateral head and therefore a pressure of 5 psi in the main line is adequate. If the difference is more than 30%, the next higher pressure in the main line must be taken into the computation.

For design of the main line, a sprinkler design slide rule, as distributed by Rainbird and other irrigation companies can be used. Each lateral can be taken as a single sprinkler with a known discharge and pressure. The main line is considered as a sprinkler lateral with densely spaced sprinklers. The size and capacity of the pump can then easily be computed.

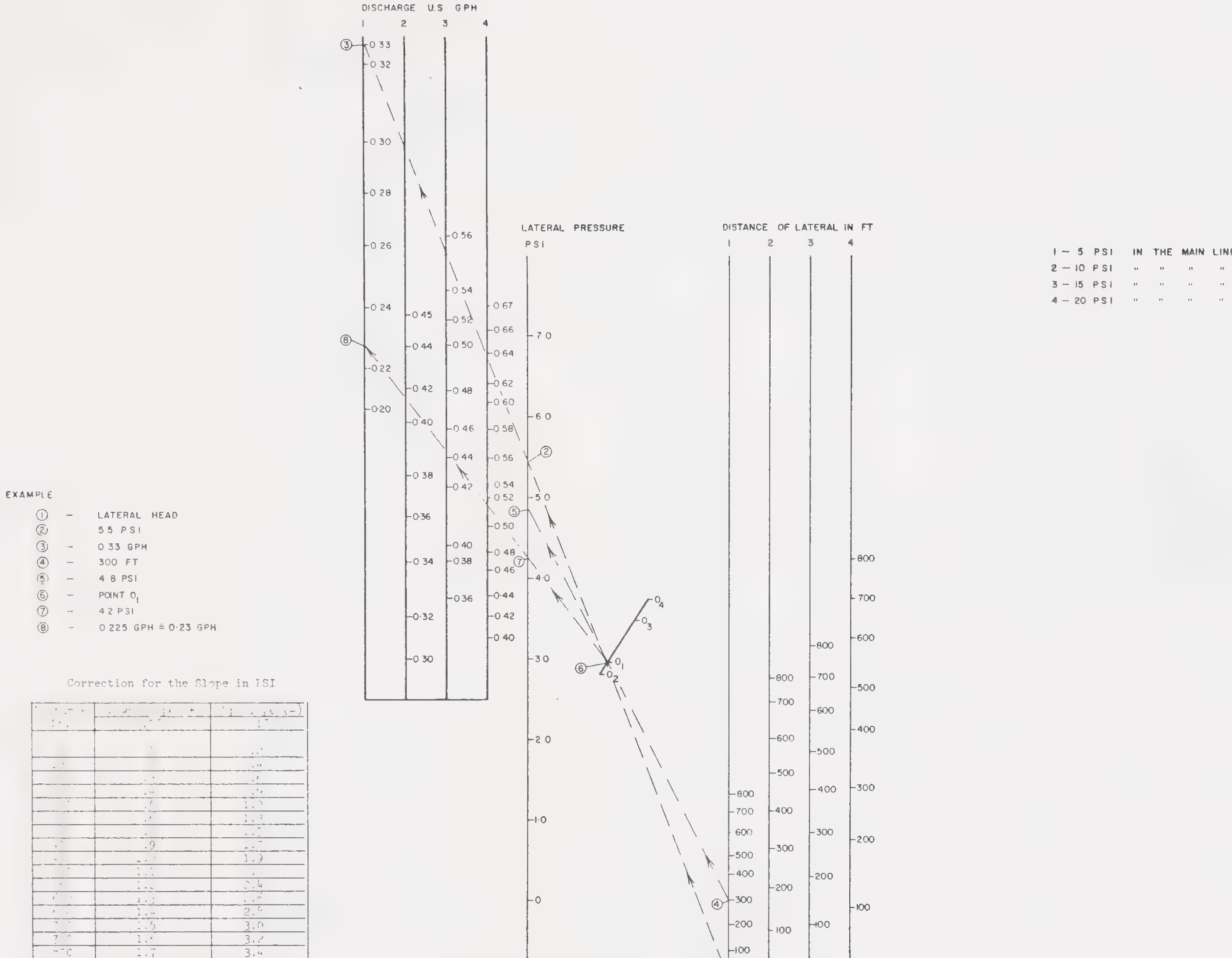
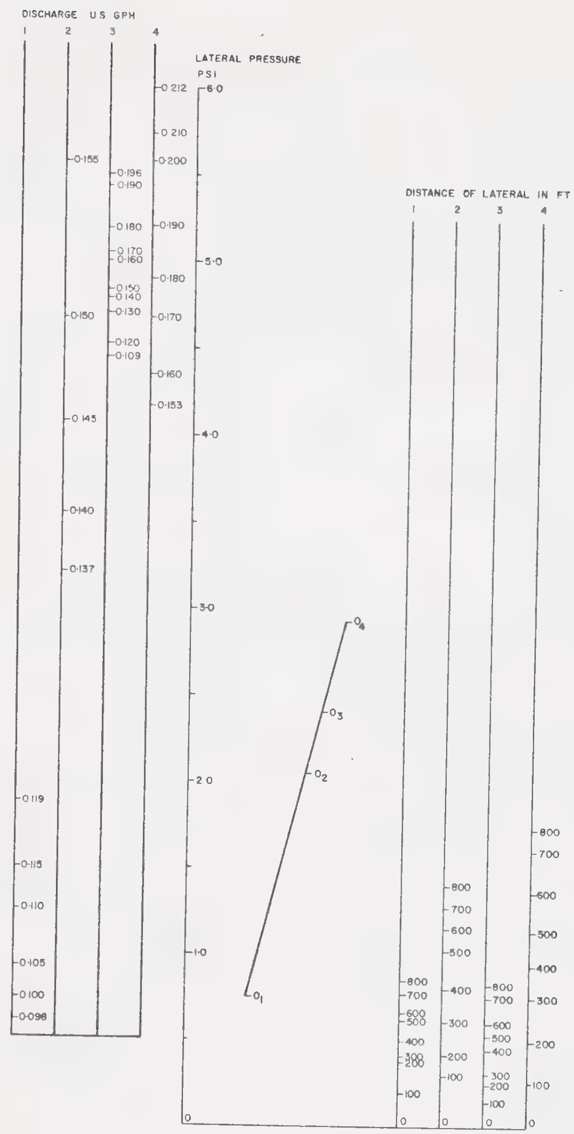


Figure 48. Nomograph for Design of Rinko Laterals.

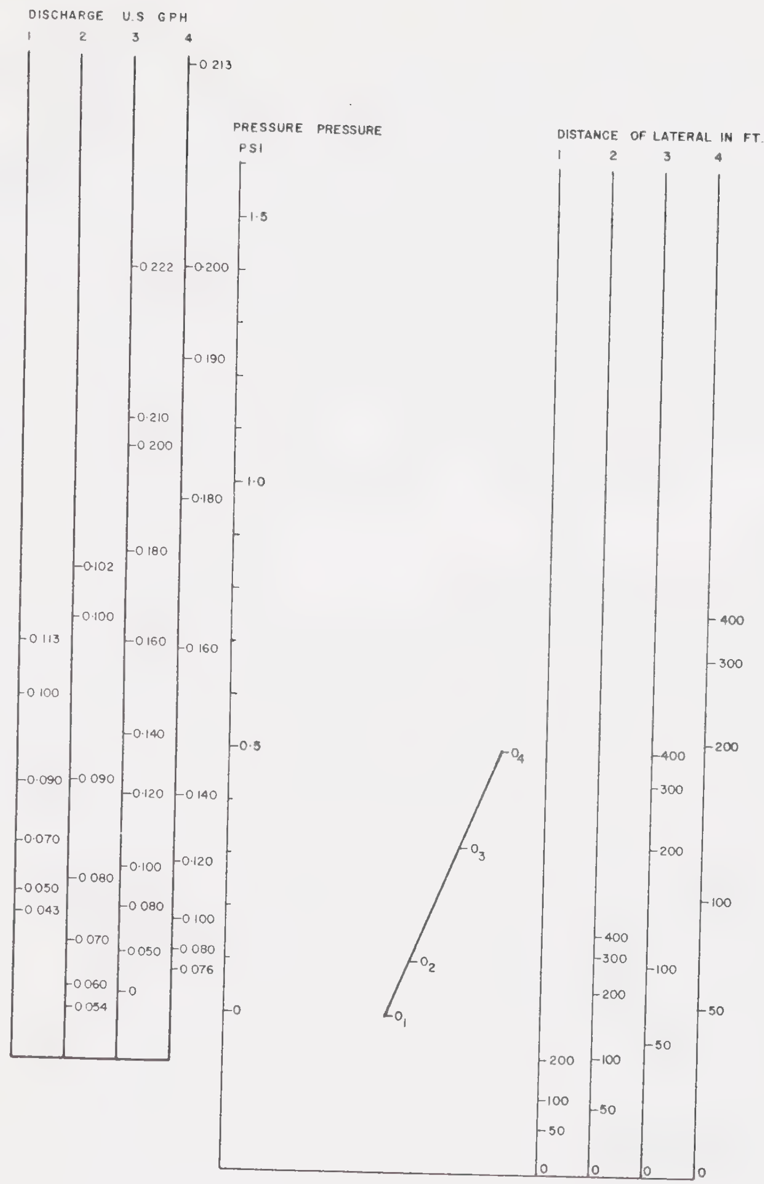


1 — 5 PSI IN THE MAIN LINE
2 — 10 PSI " " "
3 — 15 PSI " " "
4 — 20 PSI " " "

Correction for the Slope in PSI

Distance Ft.	[illegible]	[illegible]
50	.1	[illegible]
100	.2	[illegible]
150	.3	[illegible]
200	.4	[illegible]
250	.5	[illegible]
[illegible]	.6	1.3
[illegible]	.7	1.5
[illegible]	.9	1.7
450	1.0	1.9
500	1.1	2.2
550	1.2	2.4
600	1.3	2.6
650	1.4	2.8
700	1.5	3.0
750	1.6	3.2
800	1.7	3.4

Figure 49. Nomograph for Design of Anjac Bi Wall Laterals.

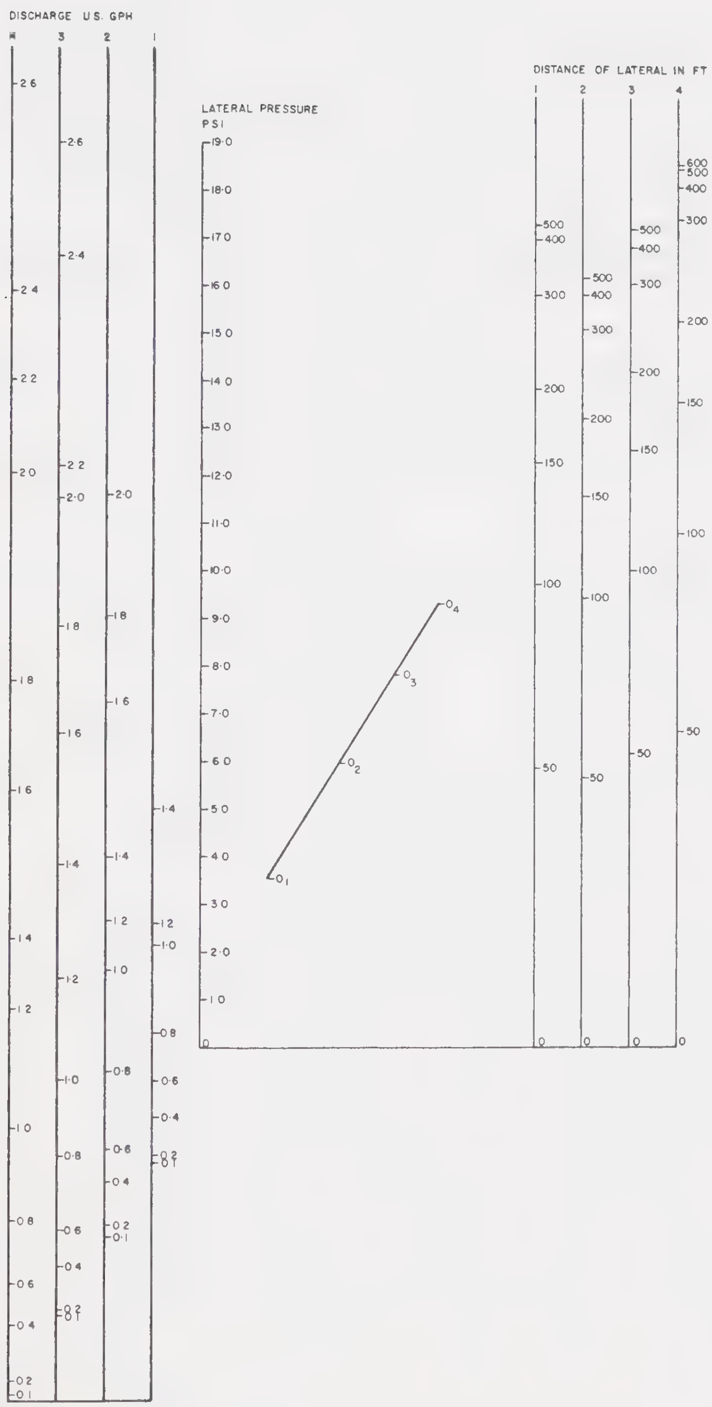


1	—	5	PSI	IN THE MAIN LINE	
2	—	10	PSI	"	" " "
3	—	15	PSI	"	" " "
4	—	20	PSI	"	" " "

Correction for the Slope in PSI

Distance Ft.	Down Slope (+) .5%	Up Slope (-) [illegible]
50	.1	[illegible]
100	.2	.4
[illegible]	.3	.6
[illegible]	.4	.9
250	.5	1.0
300	.6	1.3
350	.7	1.5
400	.9	1.7
450	1.0	1.9
500	1.1	[illegible]
550	1.2	2.4
600	1.3	2.6
650	1.4	2.8
700	1.5	3.0
750	1.6	[illegible]
800	1.7	3.4

Figure 50. Nomograph for Design of Chapin Double Wall Laterals.



1 - 5 PSI IN THE MAINLINE
2 - 10 PSI " " "
3 - 15 PSI " " "
4 - 20 PSI " " "

Correction for the Slope in PSI

Distance Ft.	Down Slope (+) .5%	Up Slope (-) 1%
50	.1	.2
100	.2	.4
150	.3	.6
200	.4	.9
250	.5	1.0
300	.6	1.3
350	.7	1.5
400	.9	1.7
450	1.0	1.9
500	1.1	2.2
550	1.2	2.4
600	1.3	2.6
650	1.4	2.8
700	1.5	3.0
750	1.6	3.2
800	1.7	3.4

Figure 51. Nomograph for Design of Submatic Laterals.

SUMMARY AND CONCLUSIONS

1. Trickle irrigation is a new method of irrigation with potential use under Alberta conditions, especially for high value crops. The spacing of laterals and drippers can be selected in cooperation with horticultural specialists. The choice of the trickle irrigation system to use should be made by an irrigation specialist.
2. Five systems were tested. Ranking on the basis of satisfactory performance, these were: Rinko, Anjac or Viaflo, Chapin Double Wall, and Submatic.
3. The Rinko system with factory-assembled laterals, was found to be trouble-free and had excellent hydraulic characteristics. These advantages tend to outweigh the higher price of the system.
4. The Anjac Bi Wall system performed fairly well. Also, the low price for the system is attractive. The manufacturer offers different spacing of orifices, both for the inner and for the outer hoses. However, variations in discharge may cause problems with the crops which require exacting irrigation applications and where a high uniformity of discharge is desirable. In this case, a more precise system may be necessary.
5. The Viaflo system appears to be a very precise system for very slow and continuous irrigation. The system is suitable for laterals up to 400 ft long. Handling of the system should be kept to a minimum because breakages can easily occur, especially after the system has been in operation for some time. Pressures higher than 5 psi in the main line are not recommended. The

system appears to operate only when the hose is touching the surface of the soil. Laterals which are buried shallow are therefore desirable. The weight of the soil will also prevent the lateral from blowing in a strong wind. Water soluble fertilizer does not have any apparent influence on the system. No plugging of the pores was observed.

6. The Chapin Double Wall system is an inexpensive system and gave relatively good performance. The variation in discharge was similar to the problem with the Anjac Bi-Wall. It was not possible to obtain a high uniformity with this system. For the crops of tomatoes, cucumbers and carrots, however, no qualitative difference between the first plants and last ones in a row were observed. This problem could be serious for strawberries which are quite sensitive to over-irrigation

7. The Submatic system has high pressure losses in the laterals and is the least suitable for irrigation of long rows of vegetables. The laterals for this system are very short, especially when the field has an upgrade (see Nomograph Fig 51). The manufacturer produces different sizes of emitters so it is possible to regulate the pressure and discharge by using the larger sizes of emitters towards the bottom end of the lateral. More field experiments would be necessary to provide additional hydraulic characteristics for such a combined system.

8. Water filtration is essential to all of the above mentioned systems. Plugging of orifices is still the main problem with a trickle irrigation system. The Anjac Bi-Wall, Chapin Double-Wall,

and Viaflo are even more sensitive to plugging than any other systems. A fine felt filter would be beneficial for these systems. A 10% stoppage can be expected for both "Double Wall" systems.

9. The present adjustable systems require too much labor and the uniformity of discharge is still low. These systems are therefore not recommended for use in Alberta.

10. The systems which have glue-in type of emitters are not recommended for use unless the laterals are assembled by the manufacturer.

11. Systems, which require other than 2 ft spacing between the emitters, should be tested and similar pressure-length and discharge-length equations computed.

12. Further automation of trickle irrigation systems is possible by using proper moisture sensors, automatic valves and a self-priming pump.

APPENDIX

Table 1a: Lateral Hydraulics
System: CHAPIN DOUBLE-WALL
Mainline Pressure: 5 PSI, Water Temperature 98°F

Distance (feet)	Run #1		Run #2		Ave. Run		Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)			
0	.12	5.0	.15	4.0	.14	4.5	.07		
20	.25	6.5	.25	8.0	.26	7.25	.12		
40	.23	6.0	.25	6.0	.25	6.00	.10		
60	.23	6.5	.28	7.5	.28	7.00	.11		
80	.25	6.0	.26	7.5	.26	6.75	.11		
100	.21	6.5	.22	6.5	.22	6.50	.10	.10	.04
120	.19	5.5	.25	6.5	.22	6.00	.10		
140	.10	3.5	.10	2.5	.11	3.00	.05		
160	.06	4.5	.06	6.0	.06	5.25	.08		
180	.06	1.0	.05	1.0	.06	1.00	.02		
200	.08	4.0	.08	4.0	.09	4.00	.06	.06	.17

Average Orifice Flow U.S. gal/hr = .08

Coefficient of Uniformity (Cu) = 72.4%

Table 2a: Lateral Hydraulics
System: CHAPIN DOUBLE-WALL
Mainline Pressure: 10 PSI, Water Temperature: 71°F

Distance (feet)	Run #1		Run #2		Ave. Run		Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)			
0	.38	3.0	.38	4.0	.39	3.5	.06		
20	.47	8.0	.47	9.0	.48	8.5	.13		
40	.46	7.0	.41	7.0	.44	7.0	.11		
60	.45	8.0	.42	8.0	.44	8.0	.13		
80	.38	8.0	.35	9.0	.37	8.5	.13		
100	.32	7.0	.29	7.5	.31	7.25	.11	.11	.17
120	.29	3.0	.25	3.0	.28	3.0	.05		
140	.20	5.0	.18	7.0	.19	6.0	.10		
160	.15	5.5	.15	4.0	.15		.08		
180	.12	3.5	.13	4.0	.13		.06		
200	.16	4.0	.16	5.0	.17		.07	.06	.31
250	.10	4.5	.12	5.0	.11		.08		
300	.06	0	.15	0	.06		0	.04	.42
350	.10	8.5	.09	6.0	.10		.11		
390		4.5		5.0	0		.08	.09	.48

Average Orifice Flow U.S. gal/hr = .08
Coefficient of Uniformity (Cu) = 77.4%

Table 3a: Lateral Hydraulics
System: CHAPIN DOUBLE-WALL
Mainline Pressure: 20 PSI, Water Temperature: 91°F

Distance (feet)	Run #1		Run #2		Ave. Run		Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)			
0	.88	14	.89	14	.89	14	.22		
20	1.07	12	1.23	13.5	1.15	13	.21		
40	.91	12	.99	14	.96	13	.21		
60	.89	12	.90	13.5	.90	13	.21		
80	.80	11	.77	12.5	.79	12	.19		
100	.68	10	.69	9.5	.69	10	.16	.20	.46
120	.39	10	.56	9.0	.47	9.5	.15		
140	.43	9	.43	7.5	.43	8.25	.13		
160	.34	8.5	.32	8.5	.34	8.5	.13		
180	.29	7	.25	3.5	.28	5.25	.08		
200	.25	8	.25	7.0	.25	7.5	.12	.12	.90
250	.15	6	.12	3.5	.14	4.75	.08		
300	.12	0		4.0	.12	2.0	.03	.05	1.03
350	.34	15		12.0	.30	13.5	.21		
390				4.5	0	2.25	.04	.12	1.15

Average Orifice Flow U.S. gal/hr = .12

Coefficient of Uniformity (Cu) = 57.5%

Table 4a: Lateral Hydraulics
System: CHAPIN DOUBLE-WALL
Mainline Pressure: 30 PSI, Water Temperature: 91°F

Distance (feet)	Run #1		Run #2		Ave. Run		Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)			
0	1.49	13	1.47	14	1.48	13.5	.21		
20	1.66	13	1.72	14	1.70	13.5	.21		
40	1.55	14	1.55	13	1.56	13.5	.21		
60	1.25	14	1.33	14	1.30	14	.22		
80	1.16	14	1.15	14	1.16	14	.22		
100	.88	11	.99	12	.94	11.5	.18	.21	.76
120	.77	10	.79	11	.78	10.5	.17		
140	.60	9	.60	9	.61	9	.14		
160	.51	8	.53	10	.52	9	.14		
180	.38	7	.42	8	.40	7.5	.12		
200	.35	8	.38	8	.36	8	.13	.14	1.34
250	.26	9	.25	9	.26	9	.14		
300	.32	5	.21	5	.27	5	.08	.12	1.43
350	.31	9	.36	8	.34	8.5	.14		
390		6		6		6	.10	.11	1.36

Average Orifice Flow U.S. gal/hr = .14

Coefficient of Uniformity (Cu) = 74.5%

Table 5a: Lateral Hydraulics
System: ANJAC BI-WALL
Mainline Pressure: 5 PSI, Water Temperature: 86°F

Distance (feet)	Run #1		Run #2		Ave. Run		Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)			
0	.92	4	.93	5	.93	4	.07		
20	.97	4	.98	5	.97	4	.07		
40	.99	8	.98	6	.98	7	.11		
60	1.06	9	1.06	8	1.06	8	.13		
80	1.03	8	1.06	7	1.05	8	.12		
100	1.00	9	1.00	8	1.00	8	.13	.11	.06
120	.96	5	.96	7	.98	6	.10		
140	.93	12	.97	10	.95	11	.17		
160	.90	9	.89	7	.90	8	.13		
180	.87	8	.82	7	.85	8	.12		
200	.90	10	.88	10	.89	10	.16	.13	.17
250	.87	7	.84	6	.86	6	.10		
300	.83	4	.82	5	.83	4	.07	.10	.23
350	1.06	12	1.02	8	1.04	10	.16		
400	.96	8	.97	7	.97	8	.12	.12	.09
450	.87	9	.87	7	.87	8	.13		
500	.81	8	.84	7	.83	8	.12	.12	.23
550	.79	8	.78	6	.78	7	.11		
600	.76	8	.76	6	.76	7	.11	.11	.30
650	.80	8	.80	8	.80	8	.13		
700	.76	0	.78	4	.77	2	.03	.10	.29
750	.74	6	.67	6	.71	6	.10		
800	.63	7	.60	5	.62	6	.10	.08	.44

Average Orifice Flow U.S. gal/hr = .12
Coefficient of Uniformity (Cu) = 81%

Table 6a: Lateral Hydraulics
System: ANJAC BI-WALL
Mainline Pressure: 10 PSI, Water Temperature: 88°F

Distance (feet)	Run #1		Run #2		Ave. Run		Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)			
0	3.9	5	3.9	5	3.9	5	.08		
20	3.9	7	3.9	7	3.9	7	.11		
40	3.4	9	3.8	9	3.6	9	.14		
60	3.9	7	3.8	10	3.85	8	.13		
80	3.6	9	3.5	9	3.55	9	.14		
100	3.9	12	3.5	12	3.7	12	.19	.13	.20
120	3.8	12	3.4	11	3.6	12	.18		
140	3.8	14	3.4	13	3.6	14	.21		
160	3.2	12	3.3	11	3.25	12	.18		
180	3.2	11	3.3	11	3.25	11	.17		
200	3.5	13	3.2	13	3.35	13	.20	.19	.55
250	3.5	9	3.0	8	2.99	8	.13		
300	2.9	7	2.9	6	2.94	6	.10	.14	.96
350	3.0	12	3.1	10	3.07	11	.17		
400	3.1	11	3.1	10	3.07	10	.17	.15	.83
450	2.9	11	2.9	9	2.93	10	.16		
500	2.9	10	2.9	9	2.88	10	.15	.16	1.02
550	2.8	10	2.8	10	2.81	10	.16		
600	2.8	9	2.8	7	2.81	8	.13	.15	1.09
650	2.8	10	2.8	8	2.81	9	.14		
700	2.8	5	2.8	5	2.81	5	.07	.12	1.09
750	2.7	10	2.7	9	2.75	10	.15		
800	2.7	9	2.7	8	2.68	8	.13	.12	1.22

Average Orifice Flow U.S. gal/hr = .14
Coefficient of Uniformity (Cu) = 84.7%

Table 7a: Lateral Hydraulics
System: ANJAC BI-WALL
Mainline Pressure: 15 PSI, Water Temperature: 80°F

Distance	Run #1		Run #2		Ave. Run		Orifice	Ave. Orifice	Cumulative
Distance (feet)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
0	4.7	7	4.1	6	4.4	6	.10		
20	4.2	9	4.1	9	4.15	9	.14		
40	4.7	14	4.1	12	4.4	13	.20		
60	4.7	13	4.1	12	4.4	12	.20		
80	4.6	13	4.0	11	4.3	12	.19		
100	4.3	15	4.1	14	4.2	14	.23	.18	.20
120	4.3	15	4.0	12	4.15	14	.21		
140	4.2	16	3.9	13	4.05	14	.23		
160	4.2	14	3.9	11	4.05	12	.20		
180	4.1	13	3.8	12	3.95	12	.20		
200	4.0	15	4.0	13	4.0	14	.22	.21	.40
250	4.0	13	4.0	13	4.0	13	.21		
300	3.9	8	3.9	8	3.9	8	.13	.19	.50
350	4.1	10	4.0	8	4.05	9	.14		
400	3.9	5	4.0	4	3.95	4	.07	.12	.45
450	3.9	11	3.9	9	3.9	10	.16		
500	4.0	9	3.8	9	3.9	9	.14	.13	.50
550	3.9	6	3.8	9	3.85	8	.12		
600	3.9	7	3.8	7	3.85	7	.11	.12	.55
650	3.9	11	3.8	11	3.85	11	.17		
700	3.9	5	3.6	6	3.75	6	.08	.13	.65
750	3.8	9	3.5	9	3.65	9	.14		
800	3.8	7	3.5	7	3.65	7	.11	.13	.75

Average Orifice Flow U.S. gal/hr = .15
Coefficient of Uniformity (Cu) = 74.3%

Table 8a: Lateral Hydraulics
System: ANJAC BI-WALL
Mainline Pressure: 20 PSI, Water Temperature: 70°F

Distance (feet)	Run #1		Run #2		Ave. Run		Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)			
0	4.2	11	6.0	7	5.1	9	.14		
20	5.2	13	6.0	9	5.6	11	.17		
40	5.0	14	6.0	13	5.5	14	.21		
60	5.0	14	6.0	11	5.5	12	.19		
80	4.9	14	5.9	13	5.4	14	.21		
100	4.9	17	5.8	15	5.35	16	.25	.19	.25
120	4.8	15	5.6	14	5.2	14	.23		
140	4.4	15	5.4	15	4.9	15	.24		
160	4.2	14	5.5	14	4.85	14	.22		
180	4.1	15	5.2	15	4.65	15	.24		
200	4.5	15	5.1	14	4.8	14	.23	.23	.80
250	4.0	15	4.9	15	4.45	15	.24		
300	4.0	14	5.0	12	4.5	13	.20	.23	1.10
350	4.1	11	4.9	11	4.5	11	.17		
400	4.0	6	4.6	5	4.3	6	.08	.16	1.30
450	4.0	12	4.9	11	4.45	12	.18		
500	3.9	7	4.5	8	4.2	8	.12	.14	1.40
550	3.9	13	4.5	10	4.2	12	.18		
600	4.0	9	4.5	9	4.25	9	.14	.15	1.35
650	3.9	13	4.6	12	4.35	12	.20		
700	3.8	10	4.6	9	4.2	10	.15	.17	1.40
750	3.8	10	4.5	11	4.15	10	.17		
800	3.5	9	4.5	8	4.0	8	.13	.15	1.60

Average Orifice Flow U.S. gal/hr = 0.18
Coefficient of Uniformity (Cu) = 80.2%

Table 9a: Lateral Hydraulics
System: RINKO
Mainline Pressure: 5.7 PSI, Water Temperature: 86°F

Distance (feet)	Run #1		Run #2		Ave. Run		Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)			
0	5.50	19	5.50	20	5.50	20	0.32		
20	5.50	20	5.55	20	5.52	20	0.32		
40	5.50	20	5.57	20	5.53	20	0.32		
60	5.58	19	5.53	20	5.56	20	0.32		
80	5.41	20	5.45	20	5.43	20	0.32		
100	5.35	20	5.38	20	5.36	20	0.32	0.32	.14
120	5.25	19	5.28	19	5.26	19	0.30		
140	5.28	19	5.18	19	5.23	19	0.30		
160	4.95	18	5.00	18	4.98	18	0.28		
180	4.85	19	4.91	19	4.88	19	0.30		
200	4.80	18	4.90	18	4.85	18	0.28	0.29	.65
250	4.70	17	4.72	17	4.71	17	0.27		
300	4.45	17	4.62	17	4.54	17	0.27	0.27	.96
350	4.90	16	5.05	18	4.98	17	0.27		
400	4.72	16	4.71	16	4.72	16	0.25	0.26	.78
450	4.50	18	4.55	16	4.53	17	0.27		
500	4.35	15	4.48	16	4.42	16	0.25	0.26	1.08
550	4.35	17	4.35	15	4.35	16	0.25		
600	4.24	14	4.25	14	4.24	14	0.22	0.24	1.26
650	4.34	14	4.40	14	4.37	14	0.22		
700	4.12	14	4.35	14	4.24	14	0.22	0.22	1.26
750	4.18	15	4.20	14	4.19	14	0.22		
800	4.08	14	4.05	15	4.06	14	0.23	0.22	1.44

Average Orifice Flow U.S. gal/hr = 0.26
Coefficient of Uniformity (Cu) = 89.7%

Table 10a: Lateral Hydraulics
System: RINKO
Mainline Pressure: 10 PSI, Water Temperature: 66°F

Distance (feet)	Run #1 Pres. (psi)	Run #1 Disch. (cc/min)	Run #2 Pres. (psi)	Run #2 Disch. (cc/min)	Ave. Run Pres. (psi)	Ave. Run Disch. (cc/min)	Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
0	5.0	29	4.9	28	4.95	28	.45		
20	4.9	29	4.5	28	4.7	28	.45		
40	4.9	29	4.5	29	4.7	29	.45		
60	4.8	30	4.4	28	4.6	29	.46		
80	4.6	28	4.2	28	4.4	28	.45		
100	4.1	28	4.2	27	4.15	28	.44	.45	.80
120	4.0	27	4.0	27	4.0	27	.43		
140	3.9	26	4.0	27	3.95	26	.42		
160	3.9	25	4.0	25	3.95	25	.40		
180	3.8	27	4.0	26	3.9	26	.42		
200	3.8	25	3.9	25	3.85	25	.40	.41	1.10
250	3.8	26	3.9	24	3.85	25	.40		
300	3.6	23	3.9	23	3.75	23	.36	.39	1.20
350	3.8	24	3.5	24	3.65	24	.38		
400	3.5	22	3.5	23	3.5	22	.35	.36	1.45
450	3.2	23	3.5	22	3.25	22	.35		
500	3.0	21	3.5	21	3.25	21	.33	.34	1.70
550	3.1	21	3.4	20	3.25	20	.32		
600	3.1	20	3.4	20	3.25	20	.32	.32	1.70
650	3.1	19	3.1	19	3.1	19	.30		
700	3.2	19	2.97	20	3.2	20	.31	.30	1.75
750	3.0	19	2.90	20	3.0	20	.31		
800	3.1	21	2.84	22	3.1	22	.34	.32	1.85

Average Orifice Flow U.S. gal/hr = .36
Coefficient of Uniformity (Cu) = 88.2%

Table 11a: Lateral Hydraulics
System: RINKO
Mainline Pressure: 15 PSI, Water Temperature 61°F

Distance (feet)	Run #1		Run #2		Ave. Run		Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)			
0	6.5	38	6.9	36	6.7	37	.59		
20	6.4	38	6.4	36	6.4	37	.59		
40	6.2	36	6.2	36	6.2	36	.57		
60	6.1	36	6.1	35	6.1	36	.56		
80	6.0	35	6.0	35	6.0	35	.55		
100	5.9	35	6.0	34	5.95	34	.54	.56	.75
120	5.8	33	5.9	33	5.85	33	.52		
140	5.5	33	5.8	33	5.65	32	.52		
160	5.2	32	5.5	31	5.35	32	.50		
180	5.1	32	5.1	32	5.1	30	.51		
200	5.0	30	5.0	31	5.0	30	.48	.51	1.70
250	5.0	30	5.0	30	5.0	30	.48		
300	4.9	30	4.9	29	4.9	30	.47	.47	1.80
350	5.0	29	4.9	29	4.95	29	.46		
400	4.8	28	4.5	27	4.65	28	.44	.45	2.05
450	4.5	27	4.5	27	4.5	27	.42		
500	4.2	27	4.3	25	4.25	26	.41	.42	2.45
550	4.1	25	4.2	25	4.15	25	.40		
600	4.0	25	4.2	24	4.1	24	.39	.40	2.60
650	4.0	23	4.1	23	4.05	23	.36		
700	4.0	25	4.0	24	4.0	24	.39	.37	2.70
750	4.0	24	4.0	24	4.0	24	.38		
800	3.9	26	4.0	26	3.95	26	.41	.39	2.75

Average Orifice Flow U.S. gal/hr = .44
Coefficient of Uniformity (Cu) = 88%

Table 12a: Lateral Hydraulics
System: RINKO
Mainline Pressure: 20 PSI, Water Temperature: 81°F

Distance (feet)	Run #1		Run #2		Ave. Run		Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)			
0	7.0	44	7.0	45	7.0	44	.70		
20	7.0	43	7.0	44	7.0	44	.69		
40	6.8	44	6.8	44	6.8	44	.70		
60	6.5	42	6.1	43	6.3	42	.67		
80	6.0	42	6.2	42	6.1	42	.67		
100	5.9	41	6.1	41	6.0	41	.65	.68	1.00
120	5.9	38	6.0	40	5.95	39	.62		
140	5.5	39	5.8	40	5.65	40	.63		
160	5.2	37	5.6	37	5.4	37	.59		
180	5.1	39	5.2	37	5.15	38	.60		
200	5.0	36	5.1	36	5.05	36	.57	.61	1.95
250	4.9	36	5.0	36	4.95	36	.57		
300	4.5	34	4.8	34	4.65	34	.54	.55	2.35
350	4.6	34	5.0	33	4.8	34	.53		
400	4.2	32	4.8	32	4.6	32	.50	.52	2.40
450	4.1	33	4.2	31	4.15	32	.50		
500	4.0	30	4.1	29	4.05	30	.47	.49	2.95
550	4.0	31	4.0	29	4.0	30	.48		
600	3.9	28	3.8	28	3.85	28	.44	.46	3.15
650	4.0	30	3.9	27	3.95	28	.45		
700	4.0	28	3.8	27	3.9	28	.44	.44	3.10
750	3.9	28	3.8	29	3.85	28	.45		
800	3.9	29	3.8	29	3.85	29	.46	.45	3.15

Average Orifice Flow U.S. gal/hr = .52
Coefficient of Uniformity (Cu) = 87.4%

Table 13a: Lateral Hydraulics
System: SUBMATIC
Mainline Pressure: 5.5 PSI, Water Temperature: 74°F

Distance (feet)	Run #1		Run #2		Ave. Run		Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)			
0	5.0	86	5.4	85	5.2	85.5	1.35		
20	4.0	86	4.5	84	4.25	85.0	1.34		
40	3.5	76	3.8	76	3.65	76.0	1.20		
60	3.0	71	3.0	68	3.0	69.5	1.10		
80	2.46	61	2.46	59	2.47	60.0	.95		
100	1.88	57	2.01	55	1.95	56.0	.89	1.14	3.25
120	1.70	51	1.66	50	1.69	50.5	.80		
140	1.38	46	1.32	46	1.35	46.0	.73		
160	1.12	37	1.11	38	1.12	37.5	.60		
180	.90	36	.91	35	.91	35.5	.56		
200	.76	31	.77	31	.78	31.0	.49	.67	4.42
250	.48	21	.48	20	.48	20.5	.32		
300	.25	15	.25	16	.26	15.5	.24	.34	4.94
350	.47	20	.38	20	.43	20.0	.32		
400	.26	13	.26	13	.26	13.0	.20	.27	4.94
450	.11	11	.15	10	.13	10.5	.17		
500	.10	8	.10	8	.10	8.0	.13	.16	5.10
550	.06	6	.06	5	.06	5.5	.09	.11	5.14
600									
650									

Average Orifice Flow U.S. gal/hr = .48
Coefficient of Uniformity (Cu) = 27.8%

Table 14a: Lateral Hydraulics
System: SUBMATIC
Mainline Pressure: 10 PSI, Water Temperature: 72°F

Distance (feet)	Run #1		Run #2		Ave. Run		Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)			
0	10.5	126	10.2	122	10.4	124	1.96		
20	9.0	119	9.0	120	9.0	119.5	1.89		
40	7.8	118	7.0	112	7.4	115	1.82		
60	6.0	75	6.0	99	6.0	87	1.38		
80	5.2	80	5.2	85	5.2	82.5	1.31		
100	4.2	82	4.0	78	4.1	80	1.27	1.60	6.30
120	3.8	73	3.5	74	3.65	73.5	1.16		
140	2.68	68	2.68	65	2.68	66.5	1.05		
160	2.19	58	2.20	56	2.20	57	.90		
180	1.82	51	1.80	51	1.82	51	.81		
200	1.54	37	1.51	46	1.53	41.5	.66	.97	8.87
250	.85	29	.94	28	.91	28.5	.45		
300	.55	25	.57	25	.56	25	.40	.49	9.84
350	.58	24	.59	24	.59	24	.38		
400	.38	19	.36	17	.38	18	.28	.36	10.02
450	.20	13	.23	13	.22	13	.20		
500	.17	11	.19	11	.18	11	.17	.21	10.22
550	.11	7	.07	8	.10	7.5	.12		
600		5		3		4	.06	.11	10.30
650		6		6		6	.10	.08	

Average Orifice Flow US gal/hr = .58
Coefficient of Uniformity (Cu) = 23.4%

Table 15a: Lateral Hydraulics
System: SUBMATIC
Mainline Pressure: 15 PSI, Water Temperature: 70°F

Distance (feet)	Run #1		Run #2		Ave. Run		Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)			
0	14.0	145	14.5	147	14.25	146	2.31		
20	12.8	140	12.5	145	12.65	142.5	2.25		
40	10.5	125	10.3	139	10.40	132	2.09		
60	9.0	113	8.9	121	8.95	11.7	1.85		
80	7.5	78	7.5	107	7.50	92.5	1.46		
100	6.5	93	6.0	100	6.25	96.5	1.53	1.91	8.00
120	5.2	91	5.0	93	5.10	92	1.46		
140	4.5	80	4.3	80	4.40	80	1.27		
160	3.8	70	3.9	69	3.85	69.5	1.10		
180	2.65	66	2.67	64	2.66	65	1.03		
200	2.22	57	2.20	57	2.21	57	.90	1.21	12.04
250	.96	38	1.32	37	1.33	37.5	.59		
300	.80	30	.80	37	.81	33.5	.53	.65	13.44
350	.74	29	.75	28	.75	28.5	.45		
400	.48	20	.47	20	.48	20.0	.32	.43	13.77
450	.34	15	.29	16	.28	15.5	.24		
500	.21	13	.23	13	.23	13	.20	.25	14.02
550	.12	8	.12	7	.13	7.5	.12		
600		5		5		5	.08	.13	14.12
650		7		7		7	.11	.09	

Average Orifice Flow U.S. gal/hr = .71
Coefficient of Uniformity (Cu) = 25.6%

Table 16a: Lateral Hydraulics
System: SUBMATIC
Mainline Pressure: 20 PSI, Water Temperature: 69°F

Distance (feet)	Run #1		Run #2		Ave. Run		Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)			
0	18.5	144	18.5	173	18.5	158	2.50		
20	16.0	124	16.0	168	16.0	146	2.31		
40	13.8	147	13.1	159	13.4	153	2.42		
60	11.4	135	11.0	126	11.2	130.5	2.07		
80	9.8	110	9.7	124	9.75	117	1.85		
100	8.0	106	8.0	116	8.0	111	1.76	2.15	10.50
120	6.9	94	6.5	105	6.70	99.5	1.58		
140	5.5	88	5.5	93	5.5	90.5	1.43		
160	4.8	74	4.5	79	4.6	76.5	1.21		
180	4.0	71	3.9	72	3.95	71.5	1.13		
200	3.0	64	3.4	67	3.2	66.5	1.03	1.34	15.30
250	1.73	41	1.68	42	1.71	41.5	.65		
300	1.01	37	1.01	35	1.02	36.0	.57	.72	17.48
350	.99	32	.90	31	.95	31.5	.50		
400	.64	23	.55	23	.60	23.0	.36	.47	17.90
450	.36	19	.36	20	.37	19.5	.31		
500	.26	14	.17	15	.22	14.5	.23	.30	18.28
550	.18	8	.09	9	.14	8.5	.14		
600	.14		.06	4	.10	2	.06	.14	18.40
650	.08		.06	8	.08	4	.13	.09	18.42

Average Orifice Flow U.S. gal/hr = .80
Coefficient of Uniformity (Cu) = 24.4%

Table 17a: Lateral Hydraulics
System: DUPONT
Mainline Pressure: 5 PSI, Water Temperature: 90°F

Distance (feet)	Run #1		Run #2		Ave. Run		Orifice Disch. (US gal/hr)	Ave. Orifice Discharge for Increment (US gal/hr)	Cumulative Head Loss (psi)
	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)	Pres. (psi)	Disch. (cc/min)			
0	2.12		2.12		2.12				
20	2.07		2.16		2.12				
40	1.99		2.12		2.05				
60	2.16		2.07		2.12				
80	1.90		2.07		1.99				
100	1.94		2.03		1.99				.13
120	1.81		2.03		1.92				
140	1.94		1.99		1.96				
160	1.77		1.99		1.88				
180	1.73		1.99		1.86				
200	1.73		1.99		1.86				.26
250	1.77		1.94		1.86				
300	1.77		1.86		1.81				.31
350	1.94		1.99		1.96				
400	1.77		1.94		1.86				.26
450	1.73		1.94		1.83				
500	1.73		1.94		1.83				.29
550	1.73		1.86		1.79				.33

Average Flow U.S. gal/hr/ft = .027

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